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Research article

Characterization of Biobriquette from A Mixture of Rubber Seed Shell Charcoal with Sugar Cane Bagasse Using Variations of Adhesive Types

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A B S T R A C T

The use of energy, especially fossil fuels in the world, is increasing along with the increasing human population and increasing industrial development in various countries that use conventional energy. The way to reduce the use of conventional energy is to use renewable energy, one example of renewable energy is bio-briquettes. Bio-briquettes are solid fuels derived from the remaining organic matter that has undergone a compression process with a certain compressive force. The purpose of this study is to analyze the characteristics and determine the optimum parameters of bio-briquettes from rubber seed shell charcoal and bagasse with variations in adhesives (tapioca flour, sago flour and molasses). The ratio of charcoal to adhesive mixture is 90:10, 85:15, 80:20. The stages of research on making bio-briquettes include raw material preparation, carbonization, printing and product analysis. The results of the study showed that there were 2 characteristic parameters that met the standard values in all adhesive variations, namely moisture content and ash content, except for molasses adhesive variations with a ratio of 80:20 and the optimum parameters obtained in bio-briquettes mixed with rubber seed shell charcoal and taboo pulp using tapioca adhesive with a ratio of 90:10 with a moisture content value of 4.53%, ash content 4.78%, flying substance content 31.33%, carbon content 59.36%, calorific value 4422 cal/g, combustion rate 0.097 g/min, and drop test 30.9%.

1. INTRODUCTION

The use of energy, primarily fossil fuels, continues to increase worldwide in line with population growth and the advancement of industries in various countries that rely on conventional energy sources. [1]. Conventional energy sources are non-renewable because they require extremely long periods to form, which has raised concerns about the potential occurrence of an energy crisis [2]. One way to reduce the use of conventional energy is by utilizing renewable energy sources, one of which is bio-briquettes [3].

Bio-briquettes are compacted masses of combustible materials that can be burned and used as fuel to ignite and sustain a flame for a certain period of time [4]. Solid fuel known as bio-briquettes is made from organic waste materials that have undergone a compaction process under specific pressure [5]. Previous research conducted by Aldy et al. focused on the production of bio-briquettes using rubber seed peel as the main raw material, with tapioca flour and rubber seed charcoal powder (at a specific mesh size) serving as binders. Additionally, research by Leni Maulida et al. investigated the production of bio-briquettes made from sugarcane bagasse, also using tapioca

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flour as a binder [6,7]. Based on the aforementioned studies, agricultural, plant, and forestry wastes such as sugarcane bagasse and rubber seed shells can be utilized as raw materials for bio-briquette production, thereby enhancing the commercial value of these waste materials.

According to research conducted by Ardina Ningsih on the production of charcoal briquettes using binders such as tapioca flour and sago flour, as well as research carried out by Ahmad Lathief on bio-briquette production using molasses as a binder, it can be concluded that the type of binder used significantly influences the quality of the resulting bio-briquettes [8,9]. Based on the aforementioned explanations, this study utilizes rubber seed shell waste and sugarcane bagasse as raw materials for briquette production, employing three types of binders: tapioca flour, sago flour, and molasses. The briquette production method involves applying a pressure of 60 kg/cm² during pressing, followed by drying for three days or until a constant moisture content is achieved [10], [11].

2. PROBLEM DESCRIPTION

The increasing global demand for energy, driven by population growth and industrial development, has led to excessive reliance on conventional energy sources, particularly fossil fuels. These non-renewable energy resources require long geological periods to form and are being depleted at a much faster rate than they can be replenished. This unsustainable consumption pattern raises serious concerns about the potential occurrence of an energy crisis in the future.

In response to this challenge, the development of renewable and sustainable energy alternatives has become a critical area of research and innovation. Among the promising solutions is the use of bio-briquettes-solid fuel made from organic waste materials-which offer an environmentally friendly and economically viable alternative to conventional fuels. Agricultural and forestry wastes such as sugarcane bagasse and rubber seed shells, which are often underutilized or discarded, can be transformed into valuable energy resources through briquetting processes.

However, the quality and efficiency of bio-briquettes are significantly influenced by the type of binder used in their production. Different binders-such as tapioca flour, sago flour, and molasses-may affect physical and combustion properties, including durability, calorific value, and moisture resistance. Therefore, it is essential to investigate and compare the effectiveness of these binders in producing high-quality bio-briquettes using standardized methods, such as compaction under 60 kg/cm² pressure and drying until constant moisture content is achieved.

This study aims to address the problem of energy resource depletion by exploring the potential of agricultural waste-based bio-briquettes as a sustainable energy solution, while evaluating the impact of different binders on the overall performance of the produced bio-briquettes.

3. MATERIAL AND METHOD

3.1. Materials

The materials used in making briquettes include rubber seed shells and sugarcane bagasse as the base materials for charcoal production, and tapioca flour, sago flour, and molasses as binding agents. The equipment used in this study is divided into two categories: production equipment and testing equipment. Production equipment includes a burning drum used as a medium for the carbonization/charcoal-making process, a stove used to heat the tapioca and sago flour binders with water, a briquette mold used to shape the briquettes, a scale used to measure the weight of the briquettes, a mortar used to grind the charred rubber seed shells and sugarcane bagasse, a wooden spatula used to stir the mixture of tapioca and sago flour with water during heating, and a sieve (70 mesh) used to filter the charcoal powder. Testing equipment includes an oven used to test the moisture content of the charcoal briquettes, a bomb calorimeter used to measure the calorific value of the charcoal briquettes, a furnace used to incinerate the

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biobriquettes to determine ash content, carbon content, and volatile matter content, and a hydraulic press used in the pressing process during briquette molding.

3.2. Methodology

3.2.1. Charcoal Mixture Preparation Steps

In the preparation of the charcoal mixture, the two raw materials—rubber seed shells and sugarcane bagasse—are first cleaned and then dried under sunlight to minimize their moisture content. After drying, each raw material undergoes a carbonization process using a closed drum kiln method (Figure 1). The drum used is made of iron sheet and consists of two parts: a smaller inner drum for placing the raw materials and a larger outer drum for holding the fuel. The smaller drum has a lid, while the larger drum has a funnel-shaped opening to allow steam to escape. The space between the inner and outer drums is filled with wood as the fuel source. The combustion process lasts for 1 hour at a temperature of 600°C for rubber seed shells and 2 hours at a temperature of 300°C for sugarcane bagasse. [12],[13]. The charcoal obtained from the carbonization process is then crushed using a mortar and pestle and sieved through a 100-mesh screen to obtain fine, micro-sized charcoal powder. The two types of charcoal powder are then mixed in a 1:1 ratio.

Figure 1. Closed kiln drum

3.2.2. Bio-briquette Production Process

Bio-briquette production consists of two main components: charcoal and binder. In this study, the charcoal is composed of a 1:1 mixture of rubber seed shell charcoal and sugarcane bagasse charcoal. Three types of binders are used: tapioca flour, sago flour, and molasses. The tapioca and sago flours are mixed with water until thickened and then heated. Subsequently, the charcoal and binder mixtures are combined according to predetermined ratios and poured into cylindrical molds with a diameter of 3.5 cm and a height of 7 cm. The mixture is then pressed at a pressure of 60 kg/cm². Finally, the bio-briquettes are sun-dried for three days or until a constant moisture content is achieved. [10], [11].

3.3. Research Design

The experimental design used in this study is a Randomized Block Design (RBD) with 9 treatments and 3 replications. To determine the effect of the treatments, the data were analyzed using Analysis of Variance (ANOVA), followed by a post-hoc test using the Duncan Multiple Range Test (DMRT) at a 5% significance level to identify significant differences between treatments [14]. This study will combine the charcoal mixture with three types of binders. The binders used are tapioca flour, sago flour, and molasses.

Table 1. Research design

Charcoal ratio (%)	Kind adhesiv		
	Tapioca (T)	Sago (S)	Molasses (M)
R1 (90:10)	TR1	SR1	MR1
R2 (85:15)	TR2	SR2	MR2
R3 (80:20)	TR3	SR3	MR3

3.4. Analysis

3.4.1. Water Content

The oven method is used to determine the moisture content of the sample by weighing 5 grams of the material into a porcelain dish after measuring its initial weight. The sample is then placed in an oven at a temperature of approximately 105°C until a constant weight is achieved [15]. The moisture content is calculated using Eq. (1):

$$Water\ Content = \frac{a-b}{a} x\ 100\% \quad (1)$$

Where a is sample weight before heating (g), b is sample weight after heating (g)

3.4.2. Ash Content

A sample of 10 grams will be weighed before being placed into a porcelain crucible for ash content analysis. After being heated until it turns into charcoal and no longer produces smoke, the sample is ashed in a furnace at 550°C until it becomes ash[16]. The ash content is calculated using Equation 2:

$$\text{Ash Content} = \frac{c-a}{b} x\ 100\% \quad (2)$$

Where a is cup weight (g), b and c are sample weight and weight of cup plus sample (g)

3.4.3. Carbon Content

Fixed carbon content is calculated using equation 3. [17].:

$$\text{Carbon Content} = 100\% - (Ka + Kzt + Kb) \quad (3)$$

Where Ka is water content (%), Kzt and kb are volatile matter level (%) and ash content (%)

3.4.4. Calorific Value

Calorific value is caluculated using equation. 4:

$$\text{Nilai kalor} = \frac{tW - e1 - e2 - e3}{m} \quad (4)$$

Where:

W = Equivalent energy in a bomb calorimeter (2426 heat/°C)

e1 = Correction in calories for heat in nitric acid formation (HNO_3)

e2 = Correction in calories for heat of sulfuric acid formation (H_2SO_4)

e3 = Correction in calories for heat of combustion of wire (*wire*)

m = Mass of briquette sample (g)

3.4.5. Burning Rate

Burning rate is calculated using equation. 5:

$$\text{Burning rate} = \frac{\text{briquettss mass}}{\text{burning time}} \quad (5)$$

Where briquette is Massa briket terbakar = initial briquette mass-remaining briquette mass (g), burning time in minutes

3.4.6. Evaporation Level

The sample is placed into a porcelain crucible to test the volatile matter content. Subsequently, the sample is inserted into a furnace for 7 minutes, and the temperature is adjusted to 950±20°C.[18]. Evaporation level is calculated use equation. 6:

$$\text{Evaporation level (\%)} = \frac{a-b}{a} \text{x } 100\% \quad (6)$$

Where a and b are sample mass before heating (g) and mass after heating (g)

3.4.7. Drop Test

Drop test is calculated use equation. 7:

$$\text{Drop Test (\%)} = \frac{a-b}{a} \times 100\% \quad (7)$$

Where a and b are briquette mass before dropping (g) and Briquette mass after dropping (g)

3.4.8. Density

Density is calculated use equation. 8:

$$\text{Density (g/cm}^3\text{)} = \frac{m}{v} \quad (8)$$

Where m and v are briquette mass (g) and briquette volume (cm^3)

4. RESULTS AND DISCUSSION

4.1. Density

Density generally refers to the ratio of weight to volume[19]. Density can influence compressive strength, burning duration, and the ease of igniting the briquettes[20]. Briquettes with higher density exhibit greater compressive strength and longer burning times, but they are also more difficult to ignite [21]. The results of the density test can be observed in Figure 2.

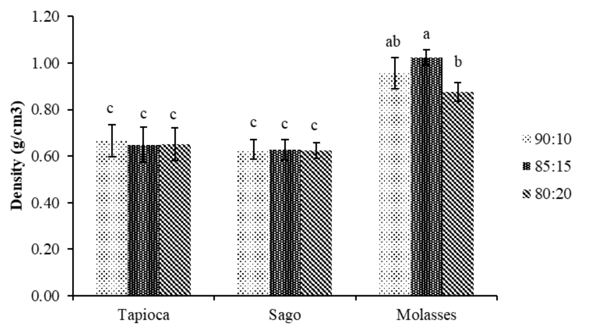

Figure 2. Value biobriquette density

Based on Figure 2, the density values for the tapioca binder samples are as follows: TR1 with a value of 0.66 g/cm³, TR2 with 0.64 g/cm³, and TR3 with 0.65 g/cm³. The density test results for the briquettes using tapioca binder show minimal variation across treatments. This is likely due to the uniform treatment applied during sieving, where all briquettes were sieved through a 70-mesh screen, and compacted under the same pressure of 60 kg/cm². Higher compaction pressure generally increases the density of the resulting briquettes[22]. As pressure increases, particles are forced into the

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voids within the briquette structure, thereby reducing porosity[23].

The density values for the sago binder samples (SR1, SR2, and SR3) are identical at 0.62 g/cm³. The density values in this variation are slightly lower than those observed in the tapioca binder variation. This difference may be attributed to the lower amylopectin content in sago flour, along with its reduced water absorption capacity, which results in weaker binding ability of the charcoal particles[24].

The density values for the molasses binder samples are as follows: MR1 with a value of 0.95 g/cm³, MR2 with 1.00 g/cm³, and MR3 with 0.80 g/cm³. The density values in the molasses binder variation are higher compared to those of the tapioca and sago binder variations. However, the density values in this variation show inconsistency, with an increase observed in sample MR2 and a decrease in sample MR3. This inconsistency in density is suspected to be due to uneven mixing of the briquette components, which were mixed manually, as well as variations in particle size, homogeneity of the charcoal and binder mixture, and the type of equipment used[25].

4.2. Water Content Testing

Moisture content refers to the amount of water present in the briquettes, expressed as a percentage [26], [27]**.** The moisture content significantly affects how easily the briquettes can be ignited [28]. The moisture content test is conducted to determine the percentage of water present in the briquettes [29]**.** Furthermore, the moisture content influences the durability, density, and storage stability of the briquettes he results of the moisture content analysis can be observed in Figure 3.

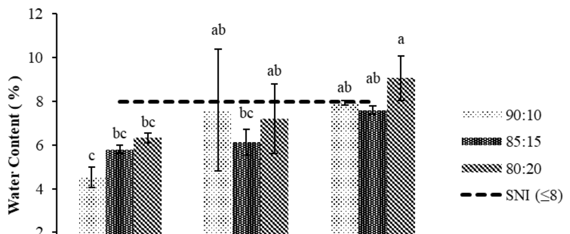

Figure 3. Value water content

Based on Figure 3, the highest to lowest moisture content values for the tapioca binder were found in sample TR3 (6.33%), followed by TR2 (5.8%), and TR1 (4.53%). From the graph, it can be inferred that an increase in the percentage of tapioca binder corresponds to a higher moisture content. All variations of bio-briquettes made with tapioca binder meet the Indonesian National Standard (SNI), which specifies a maximum moisture content of less than 8%. This aligns with Amin's research, which states that higher tapioca binder content leads to increased moisture levels [30]. Similar findings suggest that binders containing water inherently raise the overall moisture content in briquettes, as the quantity of water increases with higher binder proportions [28].

For the sago binder, the moisture content from highest to lowest was found in sample SR1 (7.60%), SR3 (7.20%), and SR2 (6.13%). Unlike tapioca, sago binder showed inconsistent trends—moisture content decreased in sample SR2 before increasing again in SR3. However, all treatments still met the SNI standard (<8%). This finding is consistent with Anizar et al., who observed a decrease in moisture content at a 30% sago binder concentration. This may be due to uneven mixing of the sago flour and charcoal during preparation, leading to varied water absorption, or incomplete drying of raw materials [25].

In the case of the molasses binder, the moisture content from highest to lowest was MR3 (9.07%), MR1 (7.93%), and MR2 (7.60%). The molasses variation showed the highest moisture content compared to tapioca and sago binders. While samples MR1 and MR2 complied with the SNI standard, MR3 exceeded the 8% threshold. This is supported by Kale et al., who studied briquettes using cow dung (solid) and molasses (liquid) as binders. Their results showed that briquettes with liquid molasses had higher moisture content than those with cow dung binder, due to the inherent water content in molasses [31]. Similarly, Elfiano found that molasses contains more water than tapioca or sago, which affects the total moisture content in briquettes during the drying process. This occurs because the outer layer of the briquette dries first, forming a strong bond with the binder, while molasses retains a relatively high amount of moisture compared to tapioca and sago [32].

It is generally assumed that lower moisture content in briquettes indicates better quality. This is supported by Smith et al., who stated that the quality of charcoal briquettes is largely determined by their moisture content [33]. The results of the ANOVA test for moisture content in bio-briquettes made from a mixture of rubber seed shell and sugarcane bagasse charcoal indicate that the ratio of charcoal to binder has no significant effect on moisture content. However, the type of binder used significantly influences the moisture level. A further post-hoc analysis using the Duncan Multiple Range Test (DMRT) at a 5% significance level confirmed these differences. As shown in Figure 3, there are statistically significant differences in moisture content among the various binder types.

4.3. Ash Content Testing

Ash content refers to the residue remaining after combustion [27]. The quality and chemical composition of the raw materials used influence the ash content [34]. A lower ash percentage indicates a higher calorific value and carbon content [16]. The type of binder used also affects the ash content [16]. The type of binder used also affects the ash content [21]. The results of the ash content analysis can be observed in Figure 4.

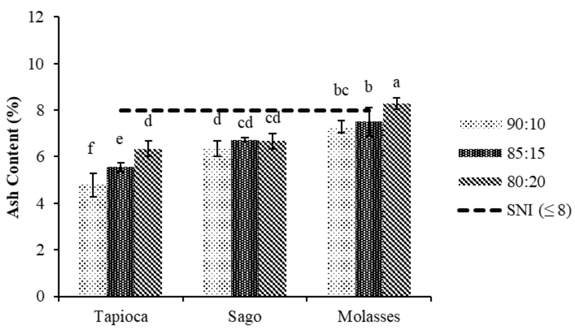

Figure 1. Ash Content Value to Ratio and Adhesive

Based on the Figure 4, the highest to lowest ash content values for the tapioca binder were found in sample TR3 (6.33%), followed by TR2 (5.56%), and TR1 (4.78%). The graph indicates that as the percentage of tapioca binder increases, the ash content also rises. All variations of bio-briquettes using tapioca binder meet the Indonesian National Standard (SNI), which specifies a maximum ash content of less than 8%. This is supported by the research of Hadijah et al., who stated that ash content is influenced by the total inorganic materials present in the raw materials and the percentage of tapioca flour used [35]. Similar findings suggest that the use of binders can increase ash content due to the addition of ash from the binder itself [36].

For the sago binder, the ash content from highest to lowest was found in sample SR2 (6.72%), SR3 (6.67%), and SR1 (6.33%). The graph shows an increase in ash content from SR1 to SR2, followed by a slight decrease in SR3. However, all treatments still comply with the SNI quality standard (<8%). According to Rahmadani, an increased amount of sago binder leads to a lower ash percentage in the briquettes. The higher ash content in sample SR2 is suspected to be due to incomplete carbonization during processing [37]. As noted by Maria et al., traditional wood burning methods tend to interact with the surrounding air, and conventional carbonization often results in higher ash content [38].

In the case of the molasses binder, the ash content from highest to lowest was MR3 (8.28%), MR2 (7.50%), and MR1 (7.28%). The graph in Figure 4.5 shows that ash content increases with higher molasses content. The molasses variation produced the highest ash content compared to tapioca and sago binders. Samples MR1 and MR2 meet the SNI standard (<8%), but sample MR3 exceeds the limit. This aligns with the findings of Nurhial et al., who reported that ash content in molasses-bonded briquettes increases with higher binder percentages [39]. A similar finding was observed in the study by Nur Faizin, which stated that the lower the charcoal content, the lower the ash content [40].

The ANOVA test results for the ash content of bio-briquettes made from a mixture of rubber seed shell and sugarcane bagasse charcoal indicate that both variables charcoal to binder ratio and type of binder significantly influence the ash content. However, the interaction between these two variables showed

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no significant effect on ash content. To further analyze the differences between treatments for both variables, a Duncan Multiple Range Test (DMRT) was conducted at a 5% significance level.

4.4. Volatile Matter Testing

During the combustion of charcoal briquettes, volatile matter is formed through the decomposition of organic compounds other than water [41]. The volatile matter content in fuel influences combustion efficiency and flame intensity [25]. Fuels with higher volatile matter content tend to ignite more easily, burn faster, and produce more smoke when lit [42,43]. The results of the volatile matter content test can be observed in Figure 5

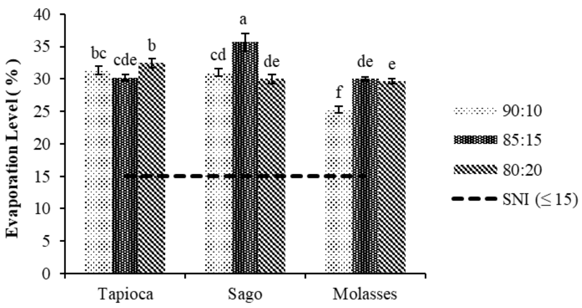

Figure 5. Volatile Matter Content Value

Based on Figure 5, the highest to lowest volatile matter content for the tapioca binder was found in sample TR3 (32.4%), followed by TR1 (31.3%) and TR2 (30.2%). The graph shows an inconsistent trend, with a decrease in volatile matter content in TR2 before increasing again in TR3. The volatile matter content of bio-briquettes made from a mixture of rubber seed shell and sugarcane bagasse charcoal using tapioca binder remains relatively high and does not meet the Indonesian National Standard (SNI) requirement of ≤ 15%. This is consistent with the findings of Yuliah et al., who reported that higher tapioca content correlates with increased volatile matter [41]. According to Sihombing et al., the amount of volatile matter released depends on the completeness of the carbonization process; longer carbonization time and higher temperatures result in greater removal of volatile substances [43].

For the sago binder, the volatile matter content from highest to lowest was SR2 (35.6%), SR1 (31%), and SR3 (30%). Similar to the tapioca binder variation, this group also exhibited inconsistencies in volatile matter content across samples. All sago binder variations still exceeded the SNI threshold of ≤ 15%. This aligns with the study by Harahap et al., which found inconsistent increases and decreases in volatile matter content for both sago and tapioca binders. This inconsistency is suspected to be due to suboptimal carbonization conditions. High temperature and sufficient duration during carbonization cause significant loss of volatile matter, resulting in relatively lower levels in the final product [44].

In the case of the molasses binder, the volatile matter content from highest to lowest was MR2 (30%), MR3 (29.6%), and MR1 (25.2%). The molasses binder variation showed relatively lower volatile matter content compared to tapioca and sago binders. According to Harlina et al., the volatile matter content plays a key role in determining combustion characteristics—higher volatile matter makes briquettes easier to ignite and burn more intensely, increasing the combustion rate [45]. While high volatile matter content facilitates ignition and combustion, it generally corresponds to lower fixed carbon content [46].

Based on the data analysis, all treatments across the different binder types showed relatively high volatile matter content, failing to meet the SNI standard of ≤ 15%. This suggests that the carbonization process used in this study was not effective, as it was conducted at an average temperature range of 300–400°C. In contrast, Rahmadani et al. suggested that an ideal carbonization temperature is around 500°C [37]. The ANOVA test results indicate a significant effect of both the charcoal-to-binder ratio and the type of binder on volatile matter content. Additionally, the interaction between these two variables also significantly influenced the volatile matter content. To further assess differences among treatments, a Duncan Multiple Range Test (DMRT) was performed at a 5% significance level.

4.5. Fixed Carbon Content Testing

Fixed carbon content is influenced by the levels of moisture, volatile matter, and ash content in the fuel [21]. The percentage of fixed carbon represents the amount of carbon remaining after all volatile substances have been removed through combustion [27]. The fixed carbon content in briquette testing is closely related to the ash content and calorific value of the briquette, making it a crucial parameter for evaluating fuel quality [47].

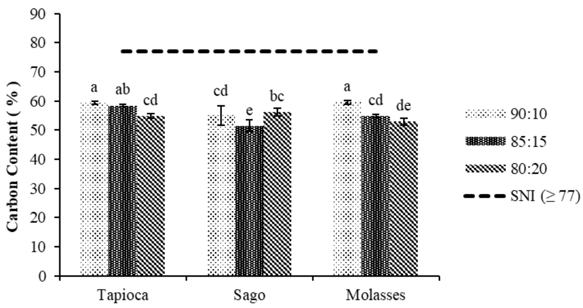

Figure 6. Carbon Content Value

Based on Figure 6, the fixed carbon content for the tapioca binder from highest to lowest was found in sample TR1 (59.3%), followed by TR2 (58.4%), and TR3 (54.8%). The data indicate a decrease in fixed carbon content as the percentage of charcoal decreases. According to SNI 01-6235-2000, a good quality briquette should have a fixed carbon content of more than 77%. However, in this study, the fixed carbon content ranged between 54% and 59%, which does not meet the standard. This aligns with Ridjayanti et al., who stated that an increase in additive materials raises ash and volatile matter content, consequently lowering the fixed carbon content [21].

For the sago binder, the fixed carbon content from highest to lowest was SR3 (56.1%), SR1 (55%), and SR2 (51.4%). The carbon content in this variation shows inconsistency, with a decline observed in sample SR2 and an increase in SR3. Similar to the tapioca binder, the sago binder variations also failed to meet the SNI standard. As charcoal concentration decreases, so does the fixed carbon content [25]. Trijati suggested that in briquette production using sago binder, higher lignin content contributes positively to the total fixed carbon [48]. Similarly, Saleh et al. noted that fixed carbon content in charcoal briquettes is influenced by both ash and volatile matter content [49]. The slight increase in fixed carbon content in sample SR3 is likely due to ineffective carbonization, where uneven temperature distribution did not reach the optimal level.

In the case of the molasses binder, the fixed carbon content from highest to lowest was MR1 (59.5%), MR2 (54.9%), and MR3 (52.9%). Similar to the tapioca binder, the fixed carbon content decreased as the charcoal percentage decreased. Based on SNI 01-6235-2000, none of the molasses binder samples met the required standard of > 77% fixed carbon. This finding corresponds with Mawarsih et al., who reported that the highest fixed carbon content in cassava peel and coconut shell briquettes with molasses binder occurred at a 5% binder concentration, while the lowest was at 9% [50].

Based on the test results across all three binder types tapioca flour, sago flour, and molasses, the fixed carbon content of the bio-briquettes did not meet the SNI requirement (> 77%). It can be concluded that higher levels of moisture, ash, and volatile matter result in lower fixed carbon content. High-quality briquettes, however, require high fixed carbon content. The ANOVA test results show that both the charcoal-to-binder ratio and the type of binder significantly affect fixed carbon content. Moreover, the interaction between these two variables also significantly influences the fixed carbon content. To further assess differences among treatments, a Duncan Multiple Range Test (DMRT) was conducted at a 5% significance level.

4.6. Calorific Value Testing

The calorific value is a crucial characteristic that determines the quality of charcoal, particularly in terms of its usability as fuel [16]. It represents the amount of heat energy released when a unit mass of fuel undergoes complete combustion [51]. Briquettes with higher calorific values are considered to be of better quality [52].

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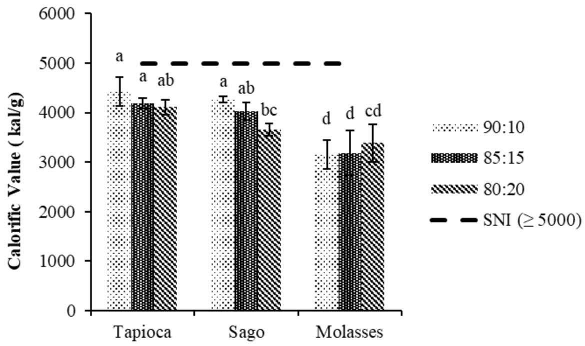

Figure 7. Calorific Value

Based on Figure 7, the calorific values for the tapioca binder from highest to lowest were found in sample TR1 (4422 cal/g), followed by TR2 (4190 cal/g), and TR3 (4112 cal/g). The calorific value in this variation shows a decreasing trend as the percentage of binder increases. This aligns with Zanella's statement that bio-briquettes with higher calorific values can be achieved by using minimal binder during production[53]. According to Muzakir et al., the calorific value of bio-briquettes is influenced by moisture and ash content higher levels of both result in lower calorific value [30].

For the sago binder, the calorific values from highest to lowest were SR1 (4263 cal/g), SR2 (4028 cal/g), and SR3 (3654 cal/g). Similar to the tapioca binder variation, an increase in binder percentage resulted in a decrease in calorific value. This is supported by Rahmadani's findings, which state that increasing ash content reduces fixed carbon content, thereby lowering the calorific value of briquettes [37].

In the case of the molasses binder, the calorific values from highest to lowest were MR3 (3385 cal/g), MR2 (3185 cal/g), and MR1 (3149 cal/g). The calorific values in this variation are relatively lower compared to those of tapioca and sago binders. According to Pratama et al., molasses has the highest moisture content among the three binders, making it difficult for briquettes made with molasses to meet SNI standards in terms of calorific value [54].

The calorific value test results for all variations of bio-briquettes made from a mixture of rubber seed shell and sugarcane bagasse charcoal did not meet the quality criteria specified in SNI 01-6235-2000 , which requires a minimum calorific value of > 5000 cal/g. The ANOVA test results indicate that there is no significant effect of the charcoal-to-binder ratio , but there is a significant effect of the type of binder on the calorific value. Furthermore, the interaction between these two variables showed no significant influence on the calorific value of the bio-briquettes. To further examine differences between treatments, a Duncan Multiple Range Test (DMRT) was conducted at a 5% significance level.

4.7. Burning Rate Testing

Combustion rate refers to how quickly a bio-briquette burns completely. In other words, the higher the combustion rate, the faster the briquette is consumed during burning [55]. The combustion rate testing involves igniting the bio-briquette to determine how long the fuel can sustain combustion. After burning, the remaining mass is weighed to calculate the amount of fuel consumed over time [56].

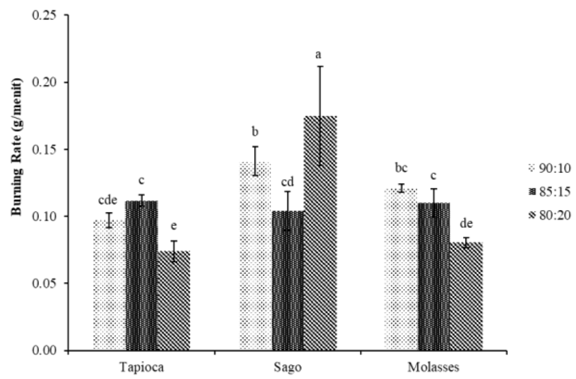

Figure 8. Burning Rate Value

Based on Figure 8 , the combustion rate values for the tapioca binder from highest to lowest were found in sample TR2 (0.112 g/min), followed by TR1 (0.097 g/min) , and TR3 (0.074 g/min). The combustion rate in the tapioca binder variation was lower compared to the other binder variations. This is likely due to the relatively lower density of the tapioca-based briquettes. This finding is consistent with the study conducted by Iriany et al., which stated that briquettes with higher bulk density are more compact than those with lower density, resulting in a longer burning time for denser or smoother-textured briquettes [57]. The combustion temperature during the burning of tapioca-bonded bio-briquettes can be observed in Figure 9.

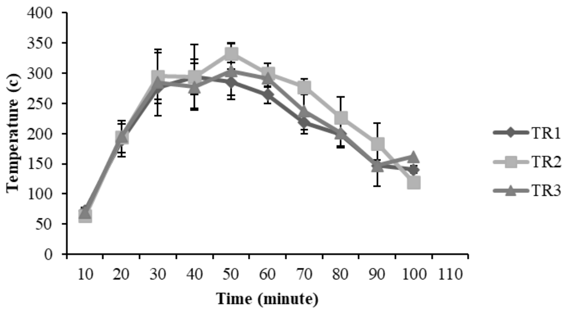

Figure 9. Tapioca Briquette Burning Temperature

Figure 9 illustrates the process of igniting briquettes with a tapioca flour binder. Based on the combustion rate test results, sample TR1 achieved the highest temperature of 294°C at the 40 minutes, with a burning duration of 1 hour and 40 minutes. Sample TR2 reached the highest temperature of 333°C at the 50th minute, with a burning duration of 1 hour and 40 minutes. Sample TR3 recorded the highest temperature of 304°C at the 50th minute, with a burning duration of 1 hour and 40 minutes.

The combustion rate values for the sago binder, from highest to lowest, are as follows: sample SR3 with a value of 0.175 g/minute, SR1 with a value of 0.141 g/minute, and SR2 with a value of 0.104 g/minute. The combustion rate for this variation is the highest compared to other variations. This is likely due to the relatively weak intermolecular bonds in sago-bound briquettes. According to Cholilie et al., an increase in the number of pores in briquettes provides ample space for oxygen penetration, resulting in a higher combustion rate [58]. The temperature during the combustion of sago-bound biobriquettes can be seen in Figure 10.

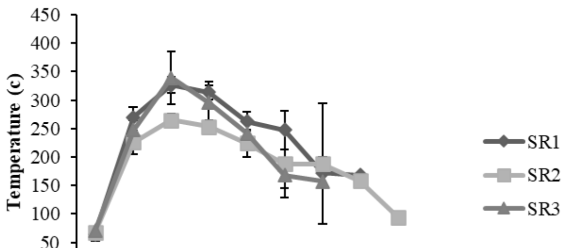

Figure 10. Sago Briquette Burning Temperature

Figure 10 depicts the process of igniting briquettes with a sago flour binder. Based on the combustion rate test results, sample SR1 achieved the highest temperature of 326°C at the 30 minutes, with a burning duration of 1 hour and 20 minutes. Sample SR2 reached the highest temperature of 265°C at the 30 minutes, with a burning duration of 1 hour and 30 minutes. Sample SR3 recorded the highest temperature of 339°C at the 30 minutes, with a burning duration of 1 hour and 10 minutes.

The combustion rate values for the molasses binder, from highest to lowest, are as follows: sample MR1 with a value of 0.121 g/minute, MR2 with a value of 0.110 g/minute, and MR3 with a value of 0.080 g/minute. The combustion rate for the molasses binder decreases as the binder percentage increases. This is consistent with the research by Ismayana and Afriyanto, which demonstrated that higher binder concentrations result in lower combustion rates [59]. The high organic content in the binder slows the combustion rate and makes the briquettes denser, which makes burning more difficult [60].

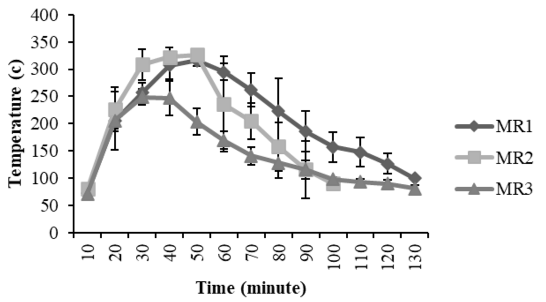

Figure 11. Molasses Briquette Burning temperature

Figure 11 illustrates the process of igniting briquettes with a molasses binder. Based on the combustion rate test results, sample MR1 achieved the highest temperature of 316°C at the 50 minute, with a burning duration of 2 hours and 10 minutes. Sample MR2 reached the highest temperature of 326°C at the 50 minute, with a burning duration of 1 hour and 40 minutes. Sample MR3 recorded the highest temperature of 249°C at the 30 minute, with a burning duration of 2 hours and 10 minutes.

Although there is no standard for measuring the quality of bio-briquettes based on their combustion

https://doi.org/ 10.25077/metal.9.2.63-77.2025

rate, a good bio-briquette is one that sustains a long burning process. The lower the combustion rate of the bio-briquette, the better the product [61]. The analysis of variance (ANOVA) test results for the combustion rate showed no significant impact from the charcoal-to-binder ratio, but a significant impact from the type of binder. Additionally, the interaction between the two variables indicated an influence of both the charcoal-to-binder ratio and the type of binder on the combustion rate of the biobriquettes. To determine the differences between treatments for both biobriquette variables, further testing was conducted using the Duncan Multiple Range Test (DMRT) at a 5% significance level.

4.8. Drop Test

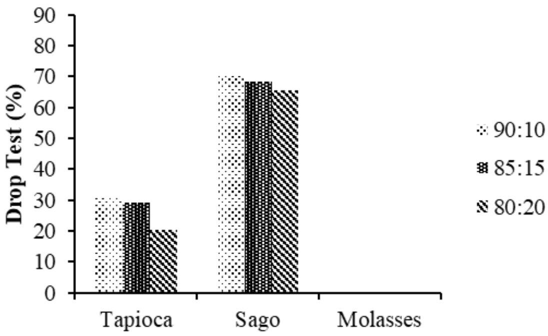

Figure 12 Drop Test

Based on Figure 12, the drop test values for tapioca binder, from highest to lowest, are as follows: TR1 with a value of 30.9%, TR2 with a value of 29.1%, and TR3 with a value of 20.2%. The test results for this variation indicate a decrease in the drop test percentage as the tapioca binder percentage increases. According to Tamrin, in a study on the production of coal briquettes using tapioca flour and clay as binding agents, it was stated that higher binder concentrations enhance the bonding strength between biobriquette particles.

The drop test values for sago binder, from highest to lowest, are SR1 with a value of 70%, SR2 with a value of 68.2%, and SR3 with a value of 65.4%. The test results for sago binder are similar to those for tapioca binder, where the drop test percentage decreases as the binder percentage increases. However, briquettes produced with sago flour variations are not as good as other variations due to the high percentage of particles lost from the briquettes after the drop test. This is consistent with the research by Anizar et al., which states that the difference in adhesive strength between sago-bound and tapioca-bound briquettes is due to the varying amylopectin content, where amylopectin contributes to the stickiness of the briquettes [25]. The amylopectin content in tapioca binder is 83%, higher than that in sago binder, which is 73%[24].

The drop test values for molasses binder differ from those for tapioca and sago binders. For all treatments of molasses-bound bio-briquettes, the drop test percentage shows excellent resistance at 0%, meaning no particles were detached from the bio-briquettes due to impact during the drop test. This is likely due to the higher density of molasses-bound briquettes compared to those bound with tapioca or sago. This aligns with the research by Harlina et al., which states that briquettes treated with molasses binder significantly impact briquette density, making molasses-bound briquettes very dense and sturdy [45]. However, briquettes with high adhesive strength may be difficult to ignite[62]

5. CONCLUSION

Based on the analysis of bio-briquette characteristics from a mixture of rubber seed shell charcoal and sugarcane bagasse charcoal using different types of binders, two characteristic parameters were found to meet the standard values across all binder variations: moisture content and ash content . The optimum bio-briquette parameter for the mixture of rubber seed shell and sugarcane bagasse charcoal using various binders was achieved with a 90:10 ratio using tapioca flour as the binder. This composition demonstrated the best overall performance in terms of quality and compliance with established standards.

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