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Production and Characterization of Bio-Briquettes from the Cassava Stems and Bamboo Charcoal Bonded with Organic Adhesive

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ABSTRACT

This study aimed to determine the effects of a materials combination used by the waste biomass of bamboo and cassava stem mixed with a tapioca adhesive on the quality of charcoal briquettes. The briquettes were made with a combination of the raw materials between the cassava stem and bamboo of 75%:25%, 50%:50%, and 25%:75%. Then, the used charcoal materials were mixed with three tapioca concentrations of 8%, 10%, and 12%. The characteristics of the charcoal briquettes, such as density, moisture content, shatter resistance index, calorific value, combustion rate, and compressive strength were observed. The charcoal briquettes with a high percentage of bamboo combination showed to increase the calorific value and the compressive strength but decreased the rate of combustion. In contrast, the low concentration of tapioca glue increased the density, compressive strength, and shatter resistance index but decreased the combustion rate. It was revealed that the used material combination and the adhesive content affected various properties of charcoal briquettes. Therefore, it can be suggested that the materials combination of bamboo and cassava stems waste can be utilized for making briquettes with a low percentage of tapioca adhesive.

1. INTRODUCTION

The existence of biomass was indicated to play an important role as an alternative source of renewable energy when fossil energy availability becomes limited [1, 2]. Tkemaladze and Makhashvili [3] reported that the utilization of biomass as renewable energy does not cause an increase in carbon dioxide in the atmosphere because it comes from biogenic sources. Earth stores a large amount of available biomass in areas ranging from forests to oceans [4]. World Bioenergy Association [5] reported that the availability of biomass and world water reserves is around 1.8 trillion tons and 4 billion tons, respectively. The world's total biomass in terms of energy has a potential production capacity of 33,000 EJ, which corresponds to more than 80 times the world's annual energy consumption [5].

Indonesia shows a high amount of biomass production that is relatively enough to be used as an energy source [2]. Some of the biomass with considerable potential is agricultural, industrial, and household waste products [6, 7]. All types of organic waste, including those mentioned above, have the potential to be developed. Food crops and plantations produce much waste that can be used for other things, such as biofuels [8]. In addition, waste products from cassava stems and bamboo have abundant amount of production.

Lampung Province has cassava production of 6,683,758 tons in 2018 with a harvested area of 256,632 ha [9]. The increase in production from 2017–2018 reached up to 22.61%. This made Lampung Province as the biggest cassava producer in Indonesia [9]. Cassava is a food crop that is a source of carbohydrates. It can use almost all plant parts, including leaves, stems, and cassava fruit. Cassava is generally harvested between 8-10 months after planting [10]. Farmers use stem cuttings from their fields after harvest in the previous season as planting material. However, only about 10% are used for replanting, and 90% of cassava stems are not yet used optimally hence become agricultural waste [11]. Cassava contains large amounts of starch (20-35% fresh and 80.6% dry weight) [12, 13] and total dry matter (38.6%) [14] and has been reported to have the smallest water footprint (21 m^3/GJ) compared to all other plants [15]. Based on the above reasons, cassava has recently received considerable attention for bioenergy production [13] and particularly for biogas production [16, 17].

In addition, bamboo is a natural resource that can be renewed quickly. Moroz et al. [18] reported that bamboo takes 4 to 5 years to grow before it is ready for use. The chemical characteristics of bamboo are composed of almost the same components as wood, namely cellulose, hemicellulose, lignin, and extractive contents [19, 20]. It shows that waste biomass from cassava stems and bamboo is very promising to be used as an alternative fuel. Therefore, adopting technology to utilize some waste products is very important, using biomass as raw materials for charcoal briquettes.

Manufacturing briquettes with a biomass mixture requires adhesives to bind the biomass particles. Previous studies show that the organic adhesive commonly used to make briquettes is tapioca flour [21]; this is supported by the ability of tapioca flour to bond the particles forming briquettes, its availability which is easy to obtain and also easy to use [22].

Sirun et al. [23] studied to determine the characteristics of briquette products, including the moisture content, combustion rate, density, and hardness, using the material combination of water hyacinth and coconut shell with variations in tapioca adhesive contents. Nasbey et al. [24] studied coconut shell briquettes using tapioca as an adhesive. They concluded that the tapioca adhesive concentration affected the briquette of the coconut shell on the compression strength and burning rate.

As mentioned above, some studies have investigated the physical and mechanical properties of briquette manufacturing using variations of tapioca adhesive content and raw materials combinations. However, in particular, there is still no study before on the charcoal briquette with variations in tapioca adhesive content using the cassava stem as the material combination. Therefore, this study aimed to determine the effects of material combination using cassava stem and bamboo with variations of cassava adhesive levels on the physical and mechanical properties of the bio-briquettes as renewable alternative energy in Indonesia.

2. METHODS

2.1 Materials

The bamboo species used to produce charcoal briquettes was betung bamboo (*Dendrocalamus asper*) of 4 to 5 years old and the 10 months of Casesart cassava species (*Manihot esculata*) was also used. Both material bamboo and cassava species were obtained from Penengahan, Natar, South Lampung Regency, Lampung Province, Indonesia. The materials used of cassava stems and bamboo is shown in Figure 1.

2.2 Charcoal briquettes manufacturing

This experiment was conducted in several stages, including preparation of tools and materials, preparation of raw materials, cooling, size reduction in stage I, size reduction in stage II, making tapioca adhesives, mixing materials, molding, and drying of briquettes. The steps of charcoal briquette manufacturing are shown in Figure 2.

Figure 1. The materials used for charcoal briquettes manufacturing. (a) Cassava stems and (b) bamboo

First, each cassava stems and bamboo were put into the drum. The drum was tightly closed and placed sideways on a parapet arranged with stones; then, the fire was burned through the bottom of the drum; when burning, the drum was tightly closed, and the smoke in the drum came out through the chimney in the drum section. The time required for composing cassava stems charcoal was 4 h, and for bamboo charcoal, it took 5 h. Then each cassava stems and bamboo charcoal were cooled at room temperature for about 30-60 m.

Each cassava stems and bamboo stick charcoal were reduced in size by using a modified lab scale hammer mill (stage I size reduction). The hammer mill machine was turned on, and each cassava stem and bamboo charcoal were added alternately until it ran out. Each cassava stems and bamboo charcoal were chopped in the tool at a speed of 1500 rpm with a sieve size of 3 meshes. The charcoal powder from each cassava stems waste and bamboo will fall through the bottom of the hammer mill; at the bottom, a trash bag was placed to accommodate the charcoal that has become powder. After reducing the size of stage I, the reduction of the size was continued to stage II, each cassava stems and bamboo charcoal powder was sifted using a 40 mesh sieve.

Figure 2. Stages of making charcoal briquettes. 1. Raw materials were put into the drum, 2. Process of coking cassava and bamboo sticks, 3. Results of coking, 4. Charcoal powder after grinding and sifting 40 mesh, 5. Briquette manufacturing, and 6. Finished and dried briquettes

After the materials changed to powder, the bamboo charcoal powder was composited with the cassava stems charcoal powder; therefore, there are variations in the composition of the raw materials in manufacturing briquettes. As for variation, the main raw material composition variations of each cassava stems and bamboo charcoal powder were divided into 75%:25%, 50%:50%, and 25%:75%.

Furthermore, each cassava stems and bamboo charcoal powder was made into a dough by adding tapioca adhesive [25], which was prepared with various adhesive concentrations of 8%, 10%, and 12%. The dough was mixed to form homogeneous briquette dough then the briquette dough was molded using a screw-type briquette manufacturer. The resulting briquettes were cylindrical in shape with a diameter of 5 cm and a length of 10 cm.

The briquettes produced from the molding generally have a surface temperature of around 40-60°C. The briquettes produced were immediately cooled in the open air with temperatures ranging from 25-28°C (room temperature). The cooled briquettes were then dried in the sun for 5-6 days in sunny weather conditions. Then the briquettes were packed in plastic and stored at room temperature for 2 weeks until further testing.

2.3 Evaluation of the charcoal briquettes

2.3.1 Density

The density (D) of samples before and after heat treatment was intended according to the following formula:

$$D = \frac{W}{V} \quad (1)$$

where, m is the weight (g) and v is the volume of samples (cm³).

2.3.2 Moisture content

The moisture content (MC) was measured by weighing the charcoal briquettes sample, then drying it in an oven at 100±5°C for 24 h. The dried samples were then cooled in a desiccator and weighed again. The MC was calculated using the following formula:

$$\mathrm{MC} = \frac{(W_1 - W_0)}{W_0} \times 100\% \quad (2)$$

where, W_1 is air dry weight (g) and W_0 is oven dry weight (g).

2.3.3 Shatter resistance index

The shatter resistance index (SRI) was measured by dropping the samples from a height onto a hard surface. The SRI was calculated using the following formula:

$$\mathrm{SRI} = 1 - (\frac{m_a - m_b}{m_a}) \times 100\% \quad (3)$$

where, m_a is the weight of the sample before the test and m_b is the weight of the sample after the test.

2.3.4 Calorific value

Calorific value is the amount of heat produced during the combustion of one unit mass of fuel with water due to combustion in steam form with units of (MJ/kg). The calorific test was performed using a bomb calorimeter (1341, Parr, Moline, United States).

2.3.5 Combustion rate

The combustion rate (CR) test was observed to determine the speed of the briquettes from smoldering to ash. First, several samples were prepared, and the weight of the briquettes was weighed before testing the combustion rate. Next, the prepared wood dipped in lamp oil was turned on the fire, and the briquettes were placed on the wire gauze until the briquettes were burning with a stopwatch. The equation used to determine the rate of combustion is explained below [26]:

$$CR = \frac{M}{t} \quad (4)$$

where, M is the weight of the samples and t is the combustion time.

2.3.6 Compressive strength

The compressive strength (σ) tests were conducted using a universal testing machine (M500-50AT, Testometric, Rochdale, United Kingdom). Measure the diameter of the samples and flatten both tips so they can stand on the measurement machine. Then pressed, the samples using the machine and counted the time until the samples broke or cracked. Afterward, the machine automatically stopped and showed the graphic and maximum value on the test. The compressive strength value was calculated using the following equation.

$$\sigma = \frac{P}{A} \quad (5)$$

where, P is the maximum test load (N) and A is the surface area (mm²).

2.4 Data analysis

The differences in density, moisture content, shatter resistance index, calorific value, combustion rate, and compressive strength among briquette combinations and among the adhesive contents were statistically analyzed with a multivariate analysis of variance. Significant differences were determined using Duncan's multiple range tests (SPSS ver. 24, IBM Corp., New York, USA).

3. RESULTS AND DISCUSSION

3.1 Density

The density of the briquette is shown in Figure 3. The average density of the briquette was in the range of 0.65-0.87 g/cm3. The lowest average density value (0.65 g/cm^3) was found in a briquette with a combination of 75% cassava stems and 25% bamboo with 12% adhesive content. While the highest average density value (0.87 g/cm^3) was found in a briquette with a combination of 25% cassava stems and 75% bamboo with 8% adhesive content. The briquette density produced in this study all complied with the SNI 8675 (2018) standard, which requires that the standard briquette density be 0.4-0.9 g/cm^3.

In this study, the density of the charcoal briquettes was affected by the combination of the raw materials used. Charcoal briquette with a combination of 25% cassava stems and 75% bamboo showed the highest density value. It is presumably due to adding more bamboo than the number of cassava stems. It could be caused by the lignocellulose content in bamboo, which is thought to be higher than in cassava stems. Roihan [27] reported that the density of composite products could be affected by the raw materials' lignocellulose content.

The tapioca adhesive concentration significantly affected the density of the briquettes. The density of briquettes decreased as the concentration of tapioca adhesive increased. It might be caused by adding water at each increase in the concentration of tapioca adhesive. Hu et al. [28] stated that the lower the concentration of tapioca adhesive used in the production of charcoal briquettes, the higher the density of charcoal briquettes. However, low density is easier to burn than the higher one because the air voids or gaps in the briquettes are getting bigger and oxygen can pass through the combustion process [25]. Additionally, the briquettes with a low density would cause them to run out quickly during combustion [29].

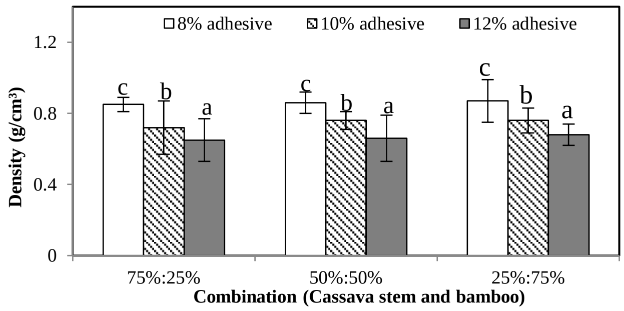

Figure 3. Effect of briquette combination and adhesive concentration on the density of charcoal briquettes (different letters within a combination show significant different at a 5% significance level between adhesive content using Duncan's multiple-range tests)

3.2 Moisture content

Figure 4 shows the moisture content of the charcoal briquettes. The average value of the charcoal briquette moisture content from this study ranged from 5.30 – 6.46%. The lowest moisture content value (5.30%) was found in the briquette combination of 75% cassava stems and 25% bamboo with 8% adhesive content. While the highest average value of moisture content (6.46%) was found in the briquette combination of 25% cassava stems and 75% bamboo with 12% adhesive content. The moisture content of the briquette produced in this study all complied with the SNI 8675 (2018) standard, which requires that the standard briquette moisture content be ≤ 8%.

The results showed that the more adhesive concentration added to the briquette material's composition, the higher the moisture content. It could be caused by adding the moisture content of the adhesive used. The moisture content of the briquettes was expected to be as low as possible to produce a high calorific value and easy ignition of briquettes. Low moisture contents produce a high calorific value [30, 31]. Conversely, the high moisture content causes the calorific value to decrease [32]. It could be caused by the energy produced being absorbed to evaporate the water; the high moisture content produces much smoke when the briquettes are burned [33].

Riseanggara [33] stated that the low amount of adhesive used increased the calorific value of the briquettes. Then, the low moisture content will make the briquettes easy to ignite and not produce much smoke when burning. Another factor that can cause low moisture content is the length of time the briquettes dry. The longer the drying time of the briquettes, the more water is wasted, so the moisture content produced will be lower [25].

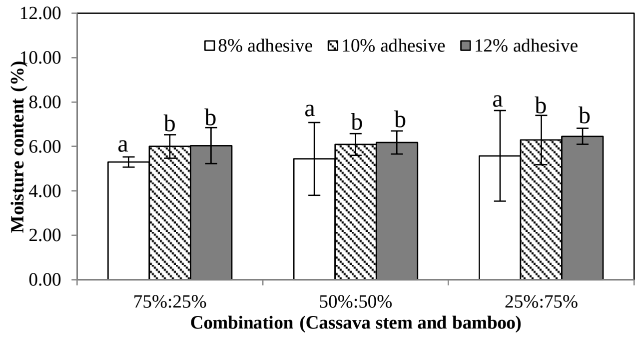

Figure 4. Effect of briquette combination and adhesive concentration on the moisture content of charcoal briquettes (different letters within a combination show significant different at a 5% significance level between adhesive content using Duncan's multiple-range tests)

3.3 Shatter resistance index

The results of testing the shatter resistance index in this study are shown in Figure 5. The briquette's shatter resistance index was 98.61-99.59%. The lowest average density value (98.61%) was found in briquette with a combination of 75% cassava stems and 25% bamboo with 12% adhesive content. While the highest average density value (99.59%) was found in briquette with a combination of 25% cassava stems and 75% bamboo with 8% adhesive content. In this study, the results of the shatter resistance index test have met the SNI 8675 (2018) briquette quality standard of 98%.

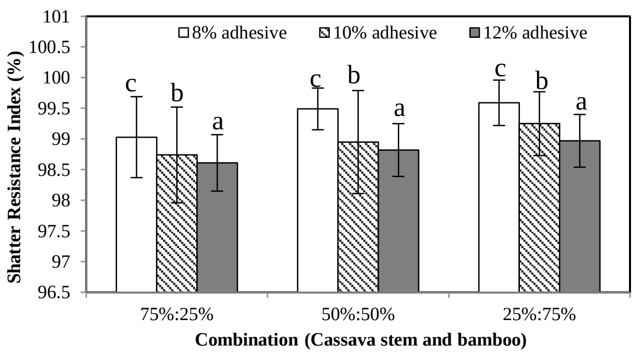

Figure 5. Effect of briquette combination and adhesive concentration on shatter resistance index of charcoal briquettes (different letters within a combination show significant different at a 5% significance level between adhesive content using Duncan's multiple-range tests)

The tapioca adhesive concentration significantly affected the shatter resistance index of briquettes. Kulig et al. [34] reported that the lower concentration of adhesive tapioca used in production briquettes would be followed by enhancement coefficient friction between the raw material particles and between the raw material particles and the screw housing and die walls during the briquette molding stage, resulting in higher molding pressures and temperatures.

3.4 Calorific value

The result of the calorific value test is shown in Table 1, respectively. The calorific value of the briquette was in the range of 5709 – 5955 MJ/kg. The lowest average density value (5709 MJ/kg) was found in a briquette with a combination of 75% cassava stems and 25% bamboo with 10% adhesive content. While the highest average density value (5955 MJ/kg) was found in a briquette with a combination of 25% cassava stems and 75% bamboo with 8% adhesive content.

Table 1. Effect of briquette combination and adhesive concentration on the calorific value of charcoal briquettes

Combination (Cassava stem and bamboo)	Adhesive content	Calorific value (cal/g)
	8%	5784 (1.23)
75%: 25%	10%	5709 (2.53)
	12%	5780 (1.81)
	8%	5786 (2.64)
50%: 50%	10%	5772 (1.49)
	12%	5710 (3.52)
	8%	5955 (3.14)
25%: 75%	10%	5793 (2.11)
	12%	5779 (1.36)

* Numbers in parentheses are standard deviations

The results showed that the calorific value of briquettes decreased with increasing the concentration of the tapioca adhesive. Tirono and Sabit [35] explained that the briquette head influences the low calorific value of briquettes. The high water and ash content of the briquette will decrease the calorific value of the briquettes produced. Bradna et al. [36] also explained that the high value of ash content could decrease the calorific value.

3.5 Combustion rate

The combustion rate is shown in Figure 6. The value of the briquette burning rate produced in this study ranged from 1.15 – 1.25 g/min, as shown in Figure 6. The lowest average density value (1.15 g/min) was found in briquette with a combination of 25% cassava stems and 75% bamboo with 12% adhesive content. While the highest average density value (1.25 g/min) was found in a briquette with a combination of 75% cassava stems and 25% bamboo with 8% adhesive content.

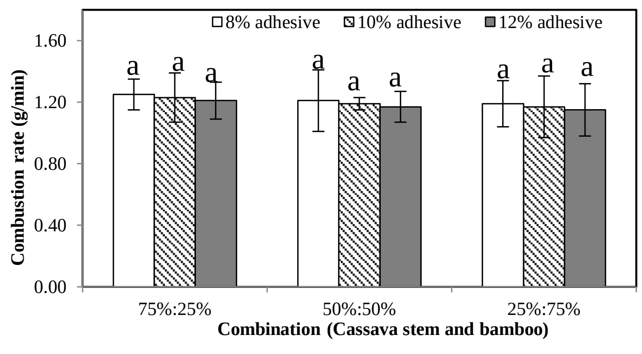

Figure 6. Effect of briquette combination and adhesive concentration on combustion rate of charcoal briquettes (different letters within a combination show significant different at a 5% significance level between adhesive content using Duncan's multiple-range tests)

The faster weight reduction will provide a large combustion rate. The greater the burning rate, the shorter the briquette flame will be. The rate of combustion is influenced by density; the lower the density produced, the longer the briquette flame will be faster. High density will result in a longer briquette flame. The rate of burning of briquettes is generally influenced by the density of the briquettes [37]. Briquettes with low porosity will have an effect to decrease the rate of combustion, while briquettes with porosity take effect to enhance the rate of burning.

3.6 Compressive strength

The results of testing the compressive strength of briquettes in this study are shown in Figure 7. The result showed the lowest compressive strength value (24.83 N/mm^2) for briquettes with the combination of 75% cassava stems and 25% bamboo with an adhesive concentration level of 12%. However, the highest compressive strength value (39.09 N/mm^2) was found in briquettes with a combination of 25% cassava stems and 75% bamboo with an adhesive concentration level of 8%. It showed that the tapioca adhesive concentration significantly affected compressive strength of the briquettes. The higher the compression strength, the higher the density of the briquettes [38]. The compression strength will affect the density that the briquettes will produce. Briquettes that are too tight will be difficult to burn, while briquettes with a low density will easily because the briquettes to decompose during combustion even though the combustion rate is very fast [39].

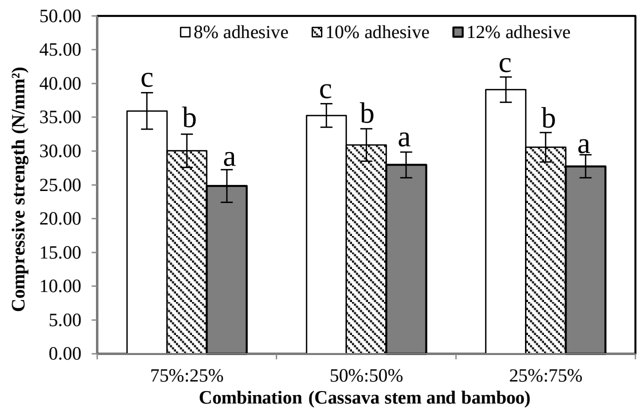

Figure 7. Effect of briquette combination and adhesive concentration on compressive strength of charcoal briquettes (different letters within a combination show significant different at a 5% significance level between adhesive content using Duncan's multiple-range tests)

4. CONCLUSIONS

There are some properties of the charcoal briquettes investigated. The calorific value and compressive strength increased with the large percentage of bamboo stem waste content, but the rate of combustion decreased. Additionally, the density, compressive strength, and shatter resistance index increased. In contrast, the combustion rate decreased with the low concentration of tapioca adhesive. It was discovered that different characteristics of charcoal briquettes were influenced by the material combination used and the adhesive content. Therefore, it can be suggested that the waste cassava stems and bamboo materials can be used to produce briquettes with a low tapioca adhesive content. However, further study using different ratios and different kinds of raw materials is considered to conduct.

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