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The effect of adding rice straw charcoal to the processing of bio-pellet from cacao pod husk

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KEYWORDS

Bio-pellet

Cacao pod husk

Calorific value

Rice straw charcoal.

ABSTRACT

Cacao pod husk and rice straw charcoal are potentially transformed into bio-pellet because of their high calorific value. Cocoa pod husk and rice straw charcoal has a calorific value of 4974.837 cal/g and 3569.837 cal/g, respectively. This research aimed to identify the effect of variations in particle size and in the addition ratio of rice straw charcoal on the calorific value of bio-pellet. Randomized block design factorial were employed in this study with factor of the addition ratio of rice straw charcoal and cacao pod husk (i.e. 0%:100%, 20% : 80%, 40% : 60%) and the particle size (i.e. 20, 40, 60 and 80 mesh). The results showed that rice straw charcoal addition resulted bio-pellet with the calorific value of 4111.93 – 4706.57 cal/g, and fulfill the SNI of bio-pellet (SNI 8021-2014). The treatment with addition of 100% cocoa pod husk and 80 mesh particle size generated the superior quality of bio-pellet. The findings confirmed that addition of rice straw charcoal did not enhance the energy potential (i.e. calorific value) of the bio-pellets, hence it is unfavourable option.

Introduction

Processing of cacao produces a lot of by-products and wastes that can be utilised into high value added products. Cacao fruit consists of 74% fruit shell, 2% placenta, and 24% seeds. Cacao pod husk is the largest production of cacao fruit and becoming waste in the surrounding environment. Currently, cacao pod husk is used as animal feed and compost (Campos-Vega et al., 2018). Meanwhile, others are left to rot around the plantation area, thus have a negative impact on the health of the cacao plant itself and the environment (Fonkeng, 2014).

Cacao pod husk usaged for animal feed should be limited because it contains theobromine that toxic to livestocks. Meanwhile, the use of cacao pod husk for compost or mulching is not suitable because it can cause fruit diseases. Usually, cacao pod husk is only buried or compiled for composting. However, at harvesting time, composting of cacao pod husk was not the best option as it can increase the emergence of cacao disease such as black pod rot (Barazarte et al., 2008). In addition, the utilization of biomass-based alternative energy is increasing because biomass energy has a relatively high heat of 3.814-4.724 kcal/kg (Munawar et al., 2014), provides environmental benefits with reduced industrial waste (Kusumaningrum et al., 2014), and biomass has fulfilled its fuel properties (Urbanovičová et al., 2017). Besides briquettes, currently bio-pellets have been developed as biomass energy, which expected to replace oil and gas fuel sources because the availability of raw materials is abundant and environmentally friendly.

Bio-pellets are sustainable bio-fuels having the characteristics of carbon-neutral, clean combustion, and more effective as an alternative fuel to replace fossil fuels in industrial combustion and power generation applications. Bio-pellet is one of the processed products from cylindrical biomass waste with a size smaller than the size of briquettes (Wibowo et al., 2018). Bio-pellet has a uniform size, shape, humidity, density, and energy content (Winata, 2013). Biopellet diameter is between 0.6-1 cm and a length of about 1.5-2 cm (Kusumaningrum et al., 2014). The compression process produces a dense material and will break when it reaches the desired length. The bio-pellet yields heat due to tool friction that facilitates the binding process of the material and decreases the material's

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water content by up to 5-10%. Bio-pellet has a higher pressure than briquettes, thus pellets have a low water content to increase the effectiveness of combustion (Bantacut et al., 2013). The perfect combustion produces if it has no indication of CO in the combustion reaction. Perfect combustion is all carbon burned out to form CO_2, and hydrogen contained is converted into water vapor.

Cacao pod husk can be used as fuel by burning directly but it has a disadvantage of poor physical properties, such as low energy (Hamzah et al., 2018); storage, and transportation problems (Artemio et al., 2018). The cacao pod husk can be transformed into a solid and uniform bio-pellet (Ungureanu et al., 2016). The characteristics of cacao pod husk is shown in Table 1.

Table 1. Characteristics of cacao pod husk

Content	Material (%)
Dry material	80.2
Ash content	9.1
Protein	5.9
Crude fiber	22.6
Crude fat	1.2
Nitrogen free	62.2
Hemicellulose	11
Cellulose	35
Lignin	14.6

sources: Sobamiwa and Longe (1994)

The straw which is a vegetative part of rice plants (i.e. stems, leaves, pan stalks) has a dry solids of 89.57%, crude protein of 3.2%, crude fiber of 32.56%, fat of 1.33 %, NDF of 67.34%, ADF of 46.40% (Sitepu, 2013). Rice straw has cellulose of 40.80%, hemicellulose of 26.62%, and lignin of 5.78%. The presence of high cellulose content makes rice straw as one of the suitable biomass for briquettes or bio-pellets. The manufacture of briquettes and bio-pellet products from rice straw waste is considered to increase the heating value of the raw material itself (Mutiara, 2015).

The calorific value becomes a determining parameter of the quality of biomass pellet. The higher the calorific value, the better the quality of the bio-pellet product. This research aimed to identify the effect of variations in particle size and in the addition of rice straw charcoal in the ratio of bio-pellet composition to the increase in the heat value of bio-pellet from cocoa pod husk.

Research Methods

Materials

Biomass materials used in this research were cacao pod husk, rice straw charcoal, cassava flour, and water.

Experimental Methods

Rice straw was sundried and charred at temperature of 400-500 °C. This process was carried out to increase the calorific value of rice straw and facilitate the mixing process in bio-pellet making. Cacao pod husk was chopped and sundried for 5 days to reduce the moisture content, then milled using hammer mill FFC37. This research used randomized block design factorial with the first factor of particle size variations and the second factor of the addition ratio of rice straw charcoal, with 3 repetitions. Particle size variations (C) consist of 4 levels; a) C1 = 20 mesh, b) C2 = 40 mesh, c) C3 = 60 mesh, d) C4 = 80 mesh. The addition ratio of rice straw charcoal to the cacao pod husk (S) include a) S0 = 0%:100% (control), b) S1 = 20% : 80%, c) S2 = 40% : 60%. Each treatment was added with adhesive cassava flour by 7% and water by 8% of the total material. The purpose of applying cassava flour as adhesive was to provide a thin layer of adhesive on the surface of bio-pellet to improve its consistency or density. With the use of adhesive, the pressure required was lower than that of in the process of pelletization. Then, the mixture materials were compressed into pellets using the TSSU hydraulic press. Each sample was measured about diameter 1 cm and length 1 cm. The biomass pellet was oven dried at 70 °C for 10 hours. The bulk density of the starting material is calculated by weighing a sample in a known volume. The moisture content is determined by drying the sample using an oven at 105 °C for 1 hour (ASTM D3171). The ash content is determined by burning in a furnace at 750 °C for 30 mins (ASTM D3174), then the fixed carbon is calculated by weight difference. The calorific value is determined to use bomb calorimeter CAL2K-HB. The apparent density is determined by dividing the mass by volume. Volume is obtained by measuring the mass and dimensions of bio-pellet with a digital weighing scale and a standard Vernier caliper. The experimental design which composed of variations in particle size and addition ratio of cacao pod husk and rice straw charcoal is shown in Table 2.

Table 2. Experimental design of variations in particle size (mesh) and addition ratio of rice straw charcoal to cacao pod husk

Particle size (C)	Rice straw charcoal addition (S)		
	100% (S0)	**20% : 80% (S1)**	**40% : 60% (S2)**
20 mesh (C1)	C1S0	C1S1	C1S2
40 mesh (C2)	C2S0	C2S1	C2S2
60 mesh (C3)	C3S0	C3S1	C3S2
80 mesh (C4)	C4S0	C4S1	C4S2

Data Analysis

Data from the results of subsequent studies were statistically analyzed by ANOVA method.

Results and Discussion

The physical characteristics of the cacao pod husk bio-pellet is shown in Figure 1. It has a cylindrical shape with a diameter of 1 cm and a length of 1 cm, brown color, cacao aroma, with a different texture on each particle size. Table 3 shows that moisture content, ash content, bulk density, a calorific value from the resulted bio-pellet fulfill the standard values of biomass pellet (SNI 8021-2014).

Density

Figure 2 describes that the smaller ratio of the cocoa pod husk component, the smaller the density. However, this study also indicates that increasing the particle size cause a reduction in density of the resulted bio-pellet. The highest density value of bio-pellet was at addition of 100% cocoa pod husk with 20 mesh with the value of 1.397 g/mL. While the smallest density was at 60% cocoa pod husk and 40% rice straw charcoal, giving the value of 1.274 g/mL.

a) 100% cacao pod husk

b) 20%:80% (rice straw charcoal :cacao pod husk)

c) 40%:60% (rice straw charcoal :cacao pod husk

Figure 1. Bio-pellet from various compositions

Table 3. The characteristics of bio-pellet

Material	Moisture content (wt, %)	Ash content (wt, %)	Volatile Matter (wt, %)	Fix Carbon (%)	Calorific Value (cal/g)	Density (g/mL)	Burning Rate (g/s)
SNI	< 12%	< 15%	< 80%	> 14%	> 4000	> 0.8	
C1S0	8.047	7.477	75.182	9.294	4308.420	1.397	148.44
C1S1	8.990	10.296	74.670	6.043	4208.130	1.382	150.58
C1S2	7.302	17.596	61.878	13.224	4166.890	1.373	156.66
C2S0	8.822	8.,209	77.515	5.454	4411.586	1.378	157.19
C2S1	9.784	12.,305	70.668	7.243	4367.969	1.377	158.,97
C2S2	8.946	20.462	60.371	10.221	4234.782	1.359	160.,65
C3S0	9.371	8.133	76.172	6.325	4640.170	1.374	145.73
C3S1	8.567	14.038	68.843	8.552	4437.536	1.284	147.38
C3S2	9.569	17.518	65.016	7.898	4278.798	1.279	149.72
C4S0	9.910	8.125	78.143	3.822	4706.570	1.371	140.17
C4S1	9.058	14.300	70.073	6.568	4470.704	1.277	143.20
C4S2	10.406	19.278	65.979	4.337	4411.925	1.274	147.81

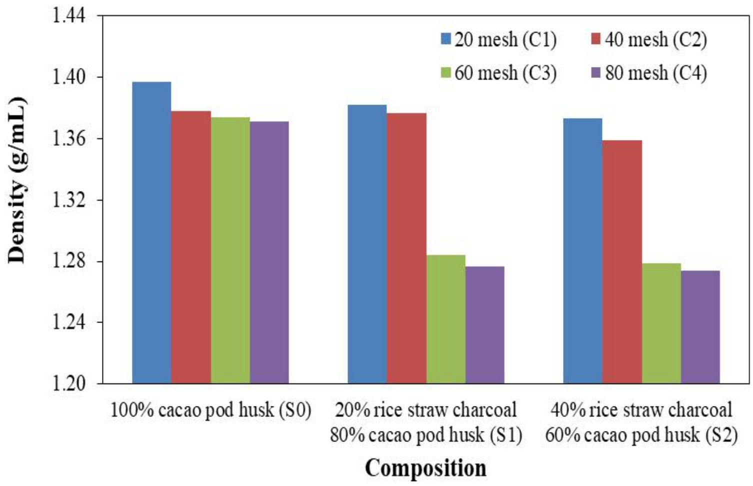

Figure 2. Density of cacao pod husk bio-pellet

The smaller the particle size, the particles can fill the void between particles and increase bonding between particles, even though the amount of material used was heavier for the same size as the small particles. The results of this study are in agreement with Harun et al. (2016). They found that the density of bio-pellets made of agricultural biomass mixed with forestry biomass was influenced by the particle size. The particle size in their study was 150-300 µm, 300 - 425 µm, and 425-600 µm (100 mesh - 29 mesh).

The more straw charcoal added to the bio-pellet mixture, the lower bio pellet density produced. The results of the density values obtained are in line with Winata (2013) research, where the increase in density values is inversely proportional to the addition of rice husk charcoal. An increase in the charcoal added causes a decrease in density value of the bio-pellet. The density value is influenced by the specific gravity of the material and the pressure given during the densification process. According to Sunardi et al. (2019), the density of briquettes affects the quality of briquettes, influenced by the particle size and homogeneity of the briquette constituent itself.

Density can also affect compressive strength, time of burning, and ease of bio-pellet ignition. If the density is too high, it can cause the bio-pellet hard to burn, while the bio-pellet with lower density can facilitate combustion. The larger the air cavity or gap that oxygen can pass through the combustion process. Bio-pellet with lower density can cause bio-pellet to run out quickly in combustion (Winata, 2013). Previous study has highlighted that the lower the material density, the faster material burns. Otherwise, the higher bio-pellet density can facilitate the handling, storage, and transportation of bio-pellet, thus it can reduce the costs needed (Adapa et al*.,* 2009). However, based on this research, the lower the material density, the compressive strength produced increases. Homogeneous particle size and material composition make the resulting bio-pellet has a low-density value but very compact, therefore the resulting compressive strength is higher with a lower combustion rate. The particle size of the bio-pellet is small (smooth), making the bio-pellet has more cavities, thus the bio-pellet is ease to burn. When testing compressive strength, the pressed material particles fill the existing space, thereforethe bio-pellet has high compressive strength and is very good for storage and transportation processes.

Ash Content

The larger the particle size of the bio-pellet and the more rice straw added, the greater the ash content. Bio-pellet with larger particle size produced more ash than that of with the smaller particle. The larger the particle size yields an amount of non-organic material for the same size of bio pellet. Therefore, the more husk, the more non-organic bio pellet material present because the husk contains high inorganic material. Rice straw ash contains up to 90% more silica (Mansaray et al*.,* 1997); SiO_2 of 82.6%, Al_2O_3 of 0.4%, and Fe_2O_3 of 0.5% (Cordeiro, 2009). In the composition cacao pod husk of 100%, the ash content of bio-pellet 20 mesh was 7.477%, size 40 mesh was 8.209%, at sizes 60 and 80 mesh the ash content decreased by 8.133% and 8.125% (Figure 3). Ash content in the resulted bio-pellet did not fulfill SNI 8021-2014 of $\leq$ 1.5%. This was possibly because cacao pod husk has a high ash content of about 11.6% (Forero-Nuñez et al., 2015). In this study, the used cacao pod husk and rice straw charcoal have ash content of 7.83% and 13.73%, respectively.

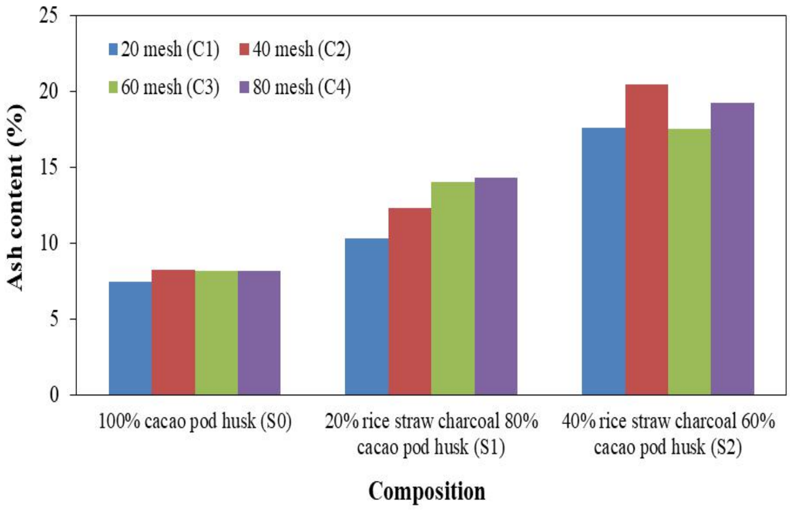

Figure 3. Ash content of cacao pod husk bio-pellet

The silica content in the material also affects the size of the ash content in the produced bio-pellet. A high silica content in the material can increase the ash content. The silica content of rice straw was 60-80% (Zaky et al., 2008). The high ash content values in the briquettes also allegedly due to carbon salts present in the raw material ingredients. Ash tends to be darker in color because it still contains unburned carbon (Bartoňová, 2015). The mixing of materials with high ash content as well as the handling process of biomass before use is considered to influence the high ash content in bio-pellet. The ash content of the lignocellulosic biomass derived carbon increased paralleled with the increasing of carbonization temperature and carbonization reaction time. The increase in ash content is the result of a progressive concentration of minerals and destructive volatilization of lignocellulosic matters as temperature increased (Lee et al., 2016).

Volatile Matter

According to Figure 4, the resulting volatile matter content ranges from 60.371% to 77.515%. The lowest volatile matter content in this study was about 60.37% produced from bio-pellet with the treatment composition of 60% cocoa pod husk and 40% rice straw charcoal with 40 mesh particle size. The highest volatile matter of about 78.14% was from addition of cacao pod husk 100% with 80 mesh particle size. This result demonstrates that the smaller the particle size causes a reduction in the volatility. Such trend was possibly because higher particle size caused a slow release of volatile substances during the combustion process as longer the combustion time is needed. The results show that the volatile matter of the produced bio-pellet decreases with an increase in the addition ratio of rice straw charcoal to the mixture. Previous study also reported that the level of evaporating substances is inversely proportional to the addition of charcoal (Winata, 2013). This is possibly due to a small percentage of volatile substances has been released during the carbonization process of rice straw charcoal (Said et al., 2015).

The adhesive concentration addition is also found to influence the level of volatile matter of bio-pellet. High levels of volatile matter can generate more smoke during the ignition of bio-pellet. The higher the volatile matter produced, the lower the combustion efficiency of bio-pellet. The findings in this study confirms that the higher the level of flying substances in the material, the lower the content of the bound carbon. The high flying substances has benefits of easier ignition and combustion, but it can lower the carbon fix content (Sunardi et al*.,* 2019).

Moisture Content

Moisture content is one of the factors that can affect the quality of bio-pellet produced, including heating value, combustion power, ease of ignition, and the amount of smoke production. The lower moisture content value indicates better quality in combustion and storage. Moreover, the high moisture content in biomass pellet can cause fungus growth, hard burning, and produce high smoke during the combustion process (Sandra et al., 2019).

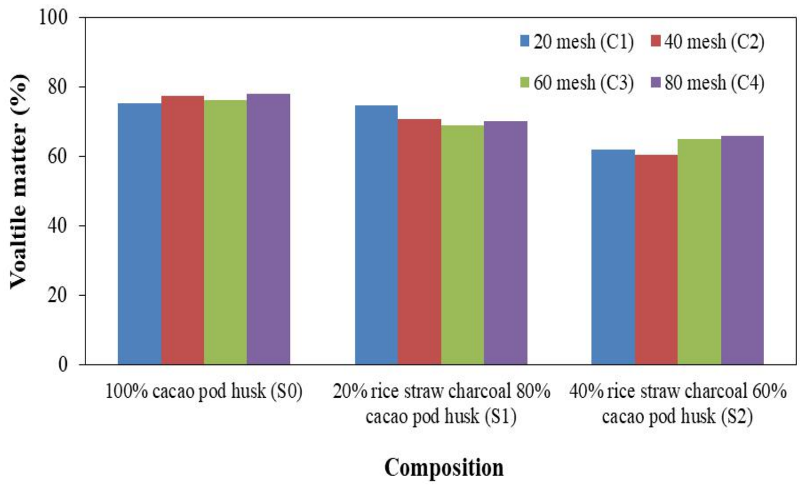

Figure 4. Volatile matter of cacao pod husk bio-pellet

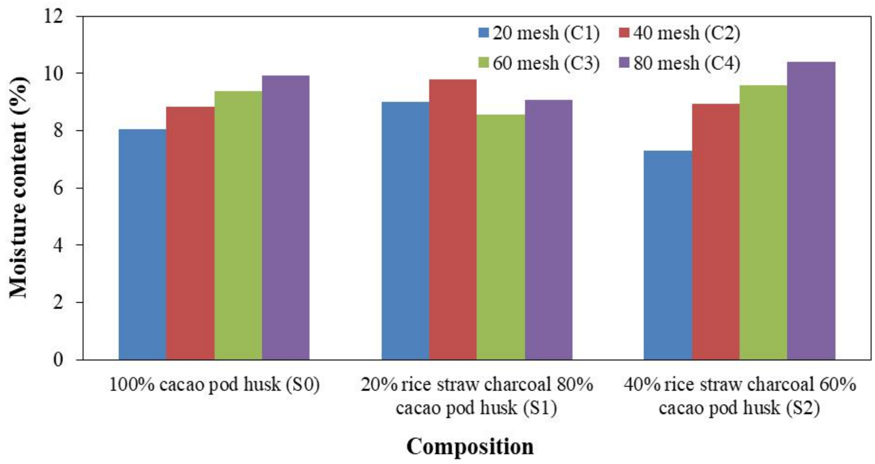

Figure 5. Moisture content of cacao pod husk bio-pellet

Figure 5 shows that the lower particle size or the delicate the particle material, the higher the moisture content of the bio-pellet produced. Decreasing the particle size of a material can increase its absorption rate. A smaller particle size can enhance the empty cavity between particles, creating more space for water to bind. Moisture content obtained in this research was ranged from 7.302% to 10.406%, meeting the SNI values of bio-pellet. The lowest water content was 7.302% obtained from treatment of 60% cocoa pod husk and 40% rice straw charcoal with 20 mesh particle size. The highest moisture content was 10.406% obtained from particle size of 80 mesh with 60%:40% of cacao pod husk and rice straw charcoal.

The moisture content of charcoal depends on the silica content, which can absorb water (Ungureanu et al., 2018). The content of silica in rice straw was 60-80% (Zaky et al., 2008). Charcoal is also easily to absorb water or charcoal has high hygroscopic properties. The water content of charcoal is influenced by the temperature and time of pyrolysis and storage, which in humid conditions can cause absorption of surrounding moisture. Charcoal with high water content can reduce the heating value, causing difficulties in ignition (Sunardi et al., 2019).

Moisture content is closely related to density of the bio-pellet and the size of the pressure press. The delicate the particles, the higher the water content, while the lower of density. The smaller the particle size of the material causes the number of air cavities in the solid, thus space is filled ease with water causing an increase the water content. According to Bahri (2008), the higher the density, the cavities between bio-pellet particles are tighter because of the solidity of particles, thus the gap or space filled with water vapor gets smaller. Bio-pellet raw materials that have low density and specific gravity can more easily absorb air from the surrounding area, causing high water content of bio-pellet.

Fixed Carbon

Levels of bound carbon or fixed carbon indicate the amount of carbon content that is anchored in briquettes and influences the evaporating agent and carbonization temperature. Previous study reported that increasing level of fixed carbon is parallel to a decrease in the level of evaporating substance (Wibowo et al., 2018).

Figure 6. shows that the smaller the particle size, the smaller the fixed carbon, and the more husk increases the fixed carbon. The highest fixed carbon content was 13.224%, with a composition cacao pod husk of 60% and rice straw charcoal of 40%, and 20 mesh particle size treatment. The lowest fixed carbon content was 3.822%, obtained from a composition cacao pod husk of 100% with 80 mesh particle size. The greater the particle size of the material, the carbonization process runs longer. The length of the carbonization process can increase the levels of carbon bound to the bio-charcoal, but the use of higher temperatures can damage the walls of the carbon pores, causing less carbon is produced (Li et al., 2008). High and low levels of fixed carbon in the material are influenced by the content of ash and flying substances, the type of biomass material, and the carbonization temperature used in the preparation and processing of bio-pellet. The higher the content of fixed carbon in the fuel, the higher the calorific value produced, while the low bound carbon content shows that the fuel quality is poor (Mutiara, 2015).

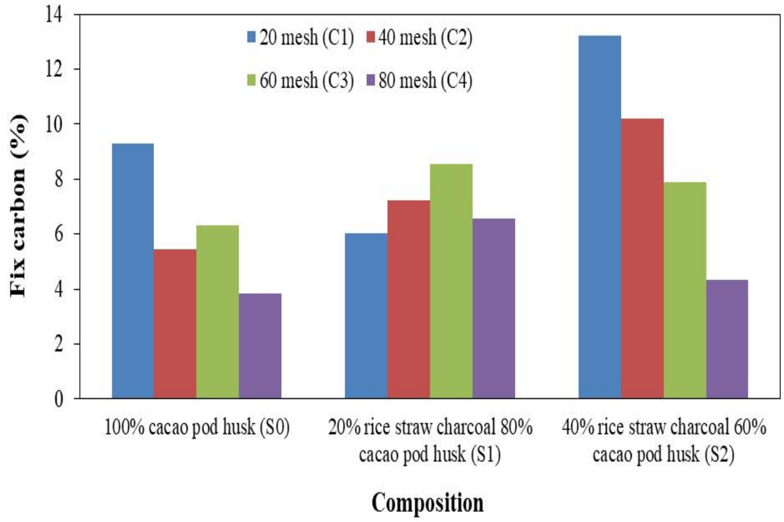

Figure 6. Fix carbon of cacao pod husk bio-pellet

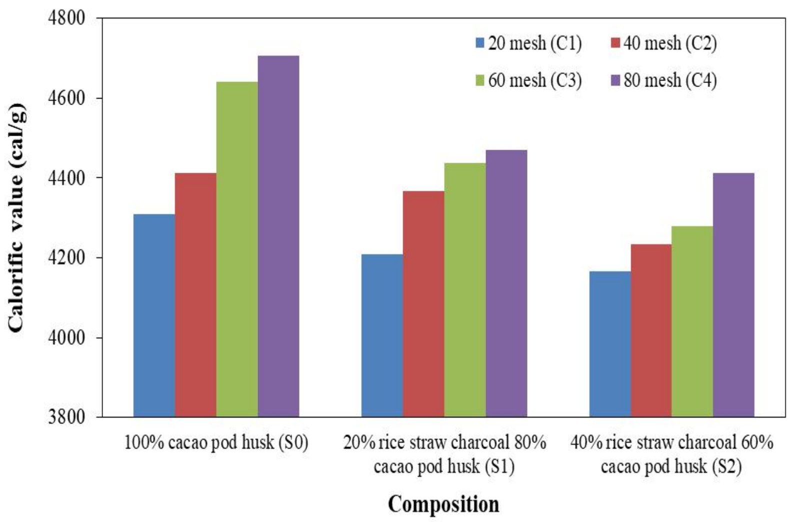

Figure 7. Calorific value of cacao pod husk bio-pellet

Calorific Value

Calorific value is one of the parameters in determining the quality of fuel, influenced by the value of the content of ash and fixed carbon. The higher the heat values, the better the fuel quality (Sandra et al., 2019). The results of the calorific value of the resulted bio-pellet are directly proportional to the carbon bound and ash content. The carbon content of the burning rate can increase heat and produce a lot of ash. Heat is also affected by moisture content, and the calorific value is inversely proportional to the water content. The higher the water content in the fuel, the lower the heat is produced (Winata, 2013).

In Figure 7, the calorific value ranges from 4166.890 to 4706.570 cal/g. The calorific value fulfills the SNI of bio-pellet. In this study, the lowest calorific value was obtained from the treatment of composition of 60% cacao pod husk and 40% rice straw charcoal, with 20 mesh particle size. The highest calorific value was resulted from composition cacao pod husk of 100% with 80 mesh particle size. The addition of rice straw charcoal to the cacao pod husk bio-pellet was considered to be less effective in this research due to its effect on reducing the calorific value. This can be influenced by a lower values of ash content, volatile matter content, and the heating value of rice straw charcoal compared to that of other materials. The high and low heating value produced depends on the type of biomass, the content of silica in the material, the temperature, and the time of carbonation used. According to Ungureanu et al. (2018), the higher water content, volatile matter, and ash content contribute to lowering the heating energy values.On the other hand, the good quality of bio-pellet can be seen from its lower water content, volatile matter, and ash. The higher levels of fixed carbon may increase the calorific values.

Burning Rate

The burning rate is the reduction in weight per unit minute during combustion. Figure 8 describes that the particle size influenced the burning rate of bio-pellet. The study found that bio-pellet made of 80 mesh particle size have the highest burning rate at all treatments.

The best burning rate of bio-pellet, with value of 140.17 s was obtained from composition of 100% cacao pod husk with 80 mesh particle size. Various factors, such as the pelleting pressure, the moisture content and the calorific value were found to affect the duration of the burning rate. The rice straw charcoal addition becomes less potential because it can slow the burning rate of the bio-pellet. High water content in bio-pellet can also slow its burning rate. Furthermore, a lower calorific value and a higher density indicate that the bio-pellet is difficult to burn. However, a less dense bio-pellet may result in the decomposition of bio-pellet during burning, giving the impression of uncleanness despite a fast burning rate (Sunardi et al., 2019).

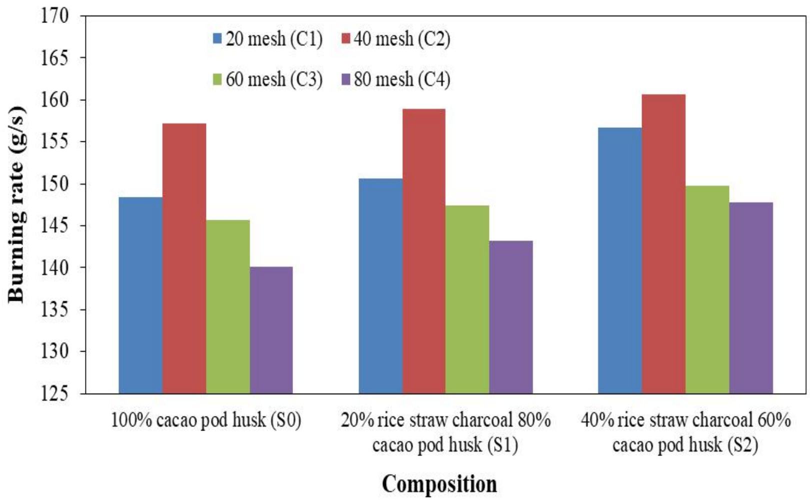

Figure 8. Burning rate of cacao pod husk bio-pellet

Conclusions

The addition of rice straw charcoal and particle size used significantly influenced the calorific value of the resulted bio-pellet. An increase in the ratio of rice straw charcoal added reduces the calorific value. The findings confirmed that a finer particle size of the materials used may increase the calorific value of the bio-pellet. The calorific value of bio-pellet with addition of rice straw charcoal was in the range of 4111.93 – 4706.57 cal/g, and these values fulfill the SNI of bio-pellet (SNI 8021-2014). The best quality bio-pellet was obtained from treatment of 100% cocoa pod husk composition with 80 mesh particle size. However, the addition of rice straw charcoal is unfavorable due to its high silica and inorganic content, as indicated from its high ash content.

Conflict of interest

The author declares that there is no conflict of interest in this publication.

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