Development of Jackfruit Peel Waste as Biomass Energy: Case Study for Traditional Food Center in Yogyakarta

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Abstract- *Gudeg* is the most famous traditional food in Yogyakarta, Indonesia, whose raw materials are jackfruit. It produces the jackfruit peel waste and causing the problems in increasing waste generation in landfills. This study aims to examine the potential of jackfruit skin waste to become waste-to-energy in the form of charcoal briquettes through the pyrolysis process. The method used is through the determination of waste generation data and fuel requirements for serving food in this traditional food central area. The researchers then conducted a proximate test on jackfruit peel waste (raw material) and jackfruit charcoal briquette products with sizes 40, 60, 80 mesh, and conducted thermal efficiency tests of micro gasification furnaces fuelled by briquette products and compared them to commonly used fuels. The results show that from the *gudeg* food center area in Yogyakarta, produce an average of 66.27 kg/day of jackfruit peel waste and that waste has the potential to be charcoal briquettes as much as 17.11 kg. Meanwhile, briquettes product using 80 mesh of jackfruit peel charcoal have the HHV of 5404 kcal/kg and have fulfilled the briquette heating value based on the Indonesian national standard No 1/6235/2000. The results of the thermal efficiency of the micro gasification stove show that the performance of this 80 mesh charcoal briquette is almost same as regular charcoal and firewood (dry based) so that the briquette has the potential as an implementation of the development of waste to energy for its own energy consumption in the traditional food center.

Keywords jackfruit peel waste; charcoal briquettes; pyrolysis; thermal properties; traditional food center.

1. Introduction

In recent years, the utilization of renewable energy becomes more attractive due to increasing energy demand and the global warming effect that is produced by fossil fuel [1]. As an agricultural country, the energy potential from biomass resources in Indonesia, especially for solid biomass waste from forestry, agriculture, and plantations, has a total 49,807.43 MW [2] and only 1740.4 MW of installed capacity of the total potential of electrical power based bioenergy resources [3].

Yogyakarta Province (DIY Province), Indonesia, located between 70.33'-80.12'South Latitude and 1100.00'-1100.50' East Longitude of Greenwich which 3,185.80 km² of the area coverage and it has a population density of 1,194 people/km² [4]. This province consists of 4 regencies and 1 city (Sleman Regency, Bantul Regency, Gunung Kidul, Regency, Kulon Progo Regency, and Yogyakarta city). The renewable energy potential from biomass in Yogyakarta has a total 1,678 TOE [5]. As a tourist destination in Indonesia for both foreign and domestic tourists, Yogyakarta has enormous biomass energy potential from organic waste, especially food waste.

Unfortunately, almost all food waste is disposed of in the Landfill named Piyungan Landfill, located in Bantul Regency and has not been utilized for waste-to-energy. Piyungan landfill has a storage capacity of 2.7 million m^3 and it can accommodate up to 450-500 tons of waste, with 200 trips/day of garbage truck [6]. Based on the initial planning design, Piyungan landfill should no longer be able to accommodate waste in 2015, but in reality, until now, this landfill still operates even though it is overcapacity, due to land limitations and high social potential from the construction of new landfills [7,8]. This landfill is dominated by organic waste with a composition consisting of 49.46% garden and park waste, 16.37% food waste, 4.07 paper and cardboard, and 0.95% wood [9].

The availability of traditional foods in Yogyakarta that already well known for foreigners plays an essential role in attracting domestic and foreigner tourists [10]. One of the high potentials of food waste generation in landfills from traditional food is jackfruit leather waste originating from the *gudeg* traditional food center. *Gudeg* is a traditional food from Central Java and Yogyakarta that is made from unripe jackfruit boiled for several hours with palm sugar and coconut milk with rice, boiled chicken, hard-boiled egg, tofu and fried bean curd [11,12]. There are two *gudeg* food centers in Yogyakarta, namely *Gudeg* Mbarek Centers in Bulaksumur, Sleman, Yogyakarta and Wijilan *Gudeg* centers in the eastern region of the Sultan's Palace in Yogyakarta [13]. Unfortunately, the waste management system in the *gudeg* center has not run well so that jackfruit peel waste from *gudeg* is wasted in landfills even though from the physical characteristics of this jackfruit peel waste can be used as raw material for biomass-based waste to energy

Various wastes of biomass have been utilized and reported by many researchers worldwide. Wastes of paddy such as rice husk, rice bran, and rice straw have been used for making briquettes by [14–17]. Briquettes from sawdust waste have been produced and evaluated by Pesa and Rajaseenivasan et al. [18,19]. Other biomass wastes also have been used for briquettes, such as a palm kernel [20], a corn cob [21], and a maize residue [22].

Regarding jackfruit waste, Sutardji et al, examined the utilization of jackfruit peel waste into bio-oil through the pyrolysis process using fixed-bed reactors at a range of temperature of 400-600°C, heating rate range between 10-50°C/min, and a range of nitrogen flow between 2-4 liter/min. The results showed that the highest bio-oil yield (52.6%) was obtained at 550°C with a nitrogen flow rate of 4 liters/min and a heating rate of 50°C/min [23]. Viswanath et al conduct the research about isolated microflora exhibited their capability to generate hydrogen while treating solid waste consisting of jackfruit peel. The biogas generation was found to be 0.72 l/g VS (jackfruit peel) destroyed. The hydrogen content in the biogas was found to be consistent resulting in The effect of HRT on volatile solids destruction efficiency 55 ± 2%, while the biogas was free from methane content [24].

Our research aims to test the potential of jackfruit peel waste originating from the Yogyakarta *gudeg* center to become charcoal briquettes through proximate testing and thermal efficiency testing of micro gasification furnaces. To regulate the quality of biomass briquettes, the Government of Indonesia released Indonesian Standard for biomass briquettes, i.e. SNI No 1/6235/2000 as given in Table 1. In order to obtain a good quality of biomass briquettes, physical and thermal properties have to be considered. Typically, the thermal properties of biomass briquettes in terms of higher heating value and combustion characteristics have to be evaluated. The several works on the evaluation of the thermal characteristics of biomass briquettes have been performed by [25–27]. The combustion time of briquettes is very affected by the composition of raw material in the briquettes [28].

Table 1. National Indonesian Standard (SNI) for Briquette production (SNI standard No 1/6235/2000)

Parameter	Standard
Water content (%)	≤ 8
Ash content (%)	≤ 8
Fixed carbon (%)	≤ 77
Heating value (cal/g)	≤5000

Although many works have been reported on biomass briquettes, none of those works tested the potential of jackfruit peel briquettes as a cooking fuel (substitutes for fossil fuel and non-briquette charcoal) for the food industry centers through proximate and ultimate tests and thermal efficiency of micro gasification furnaces.

2. Methodology

2.1 Waste generation and existing fuel sampling

The first step of this research is conducting a field survey related to data generation of jackfruit skin waste. Sampling is located at Gudek Mbarek Food Industry Center, Jalan Kaliurang KM 5, Sleman Regency, Yogyakarta, Indonesia. Data taken in the form of: (1) average mass of garbage; (2) the type of fuel, and (3) the amount of fuel used. Energy potential testing is also carried out based on calculations in equation (1) below [29,30]:

$$ERP = W \times LHV \tag{1}$$

where

ERP : Energy recovery potential (kcal)
W : Waste generation of jackfruit peel (kg)
LHV : Net calorific value of jackfruit peel (kcal/kg)

The initial stage of the research is sampling the waste from Giwangan traditional market, Yogyakarta Province, Indonesia to determine the total mass and composition of the organic waste. During the sampling process, the organic waste will be classified into three types of fruit and three types of vegetables as the representation of foods waste

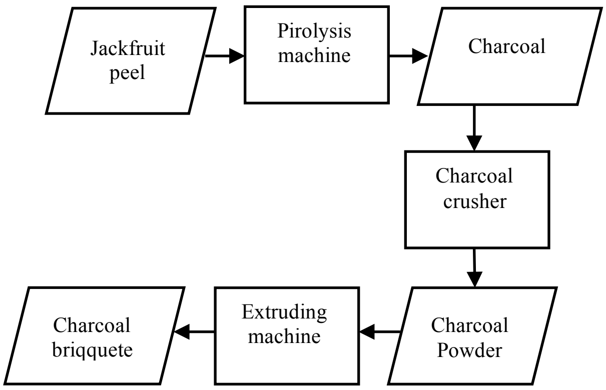
2.2 Briquette production and proximate-ultimate test

Waste of jackfruit crust is collected and sun dried. Figure 1 shows the waste of jackfruit peel. The dried peel was pyrolyzed under temperature of 500°C for 6 hours

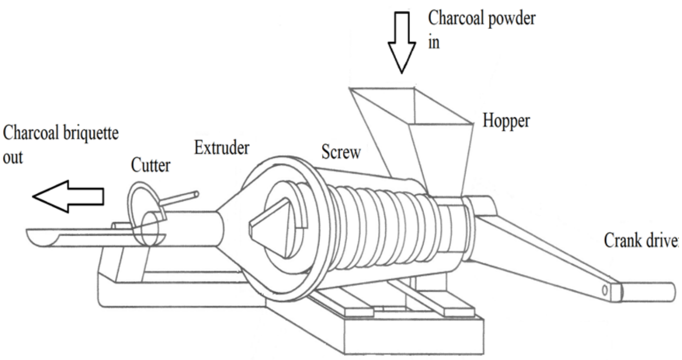
(a) (b)

Fig. 1. (a) Dried-jackfruit peel waste as raw material and (b) charcoal briquette product from jackfruit peel

The whole process for charcoal briquette production from Charcoal from jackfruit peel waste is depicted in Fig.2a. The charcoal product from the pyrolysis process using the pyrolysis machine (Fig.2c) is then crushed into small particles and meshed using 40, 60, 80 mesh size. The next process is making the briquettes from a mixture of charcoal, water, and binder of tapioca flour. The mixture is extruded using a small extruder machine (Fig.2b) to produce the briquettes. Fig.1b presents the charcoal briquettes of jackfruit crust with different sizes of the charcoal particles, i.e 40, 60, and 80 mesh.



(a)



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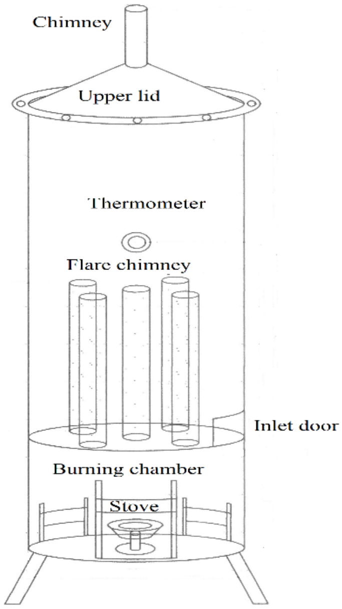


Fig. 3. (a) The making of charcoal briquettes from jackfruit peel process; (b) schematic diagram of the screw extruder machine; and (c) the pyrolysis machine

In order to investigate the thermal properties of the briquettes, proximate, ultimate, and TGA analyses are conducted. Once the composition of C, H, O, and S are obtained from the ultimate test, lower heating value (LHV) or net calorific value (NCV) of the briquettes are calculated using equation (2) below :

$$LHV = HHV * (1 - W) * E_w * (W + H * m_{H2O}) +* \Delta m_{water}$$

where

HHV : the energy content of the dry biomass released during complete combustion

E_w : the energy required for evaporation of water (2.26 MJ/kg)

W : moisture content

H : the hydrogen content (weight percent of wet fuel)

m_{H2O} : weight of water created per unit of hydrogen (8.94 kg/kg)

2.3 Thermal efficiency test of fuel

To find out the extent of the potential of this jackfruit charcoal briquette in replacing other fuels such as LPG and non-briquette charcoal commonly used for cooking *gudeg*, we conducted thermal efficiency testing using a micro gasification stove from center for energy and environmental studies of Proklamasi 45 Yogyakarta University (PSEL-UP45) production (Fig. 3). Thermal efficiency is the ratio between heat energy that is transferred to water in a container (pot) to heat water with the energy available in the fuel. This efficiency test is based on equation (3-5) as follows [31], [32]:

(3)

$$\eta_{th} = \frac{E_{pot}}{E_{fuel}}$$

$$E_{pot} = Cp_w * m_{water,i} * \Delta T + \Delta h_{H2O,fg} * \Delta m_{water} \quad (4)$$

$$E_{fuel} = \left[f_{cm} * (1 - MC) - f_{cm} * MC * \frac{[Cp_w * (T_{boil} - T_{amb}) + \Delta h_{H2O,fg}]}{LHV_{wood}} - \frac{LHV_c}{LHV_{wood}} * m_c \right] * LHV_{wood} \quad (5)$$

E_{pot} : the energy transferred to the water (kcal)
E_{fuel} † : the energy available in the fuel (kcal)
η_{th} : thermal efficiency
Cp_w : specific heat of water (kcal/kg.K)
$m_{water,i}$: the initial mass of water in the pot (kg)
ΔT : the final temperature of water minus the initial temperature of water in the pot (K)
$\Delta h_{H2O,fg}$: the heat of vaporization of saturated water at the ambient pressure (kcal)
Δm_{water} : the change in mass of water in the pot (kg)
f_{cm} : the mass of the fuel consumed during the test including the moisture in the fuel (gr)
MC : moisture content of the fuel
T_{boil} : the boiling temperature of water (K)
T_{amb} : the ambient temperature during the test (K)
LHV_c : the lower heating value of the charcoal obtained from burning the wood (kcal/kg)
LHV_{wood} : the lower heating value of the wood consumed on a dry basis (kcal/gr)
m_c : the mass of the charcoal remaining (gr)

The equipment needed for this test is a K type thermocouple for measuring water temperature and digital type scales for mass measurement of water and fuel.

3 Results and Discussion

3.1 Analysis of waste generation and energy recovery potential

Based on surveys and interviews in the Mbarek *gudeg* center, there are three restaurants that serve warm food every day. All of these restaurants produce jackfruit peel waste with a total of 66.27 kg/day (Table 2). Jackfruit peel waste is entirely discharged into the Piyungan landfill by using the garbage transport services every day. In other words, the *Gudeg* Industrial Center accounts for 24,188 kg/year in the Piyungan landfill.

(a) (b)

Fig. 3. PSEL-UP45 micro gasification stove. (a) Pre-heating briquette process; (b) briquettes that have been smoldering and ready for thermal efficiency testing

Table 2. Waste generation data and the type of fuel used for cooking at Mbarek *gudeg* center

Restaurant Name	**Jackfruit waste generation (kg)**	**ERP (Calorie)**	**Fuel type (existing)**	**Total fuel consumed (kg)**
Gudeg "H. Ahmad"	41.42	16,003.13	wood	61.80
Gudeg "Bu Lis"	20.71	8,001.56	charcoal	76.20
Gudeg "Bu Is"	4.14	1,600.31	wood	10.30
Total	**66.27**	**25,605.01**		

The existing condition of cooking fuel in the *Gudeg* industrial center shows that the three restaurants still rely on fuels in the form of charcoal and wood for the cooking process (Table 2) and there is no utilization of waste to energy from waste generated for fuel. This proves that the community of traditional cuisine enthusiasts does not understand that these two fuels tend to damage the habitat of local hardwood plants such as teak, *sengon*, and mahogany.

Proximate test results from Jackfruit peel where the HHV value and moisture content are 724.35 kcal/kg and 80.32% respectively and by using the ultimate data analysis from research conducted by Pathak et al. [33] for the amount of H (hydrogen) 5.86%, it is known that the NCV value for jackfruit peel is 386.37 kcal/kg. By using this NCV value, in theory, jackfruit peel waste from this location can produce an ERP value of 25,605.01 calories.

3.2 Physical and chemical properties Briquettes

Table 3 shows the result of the proximate and ultimate of the biochar briquettes. It is observed that ash content decreases as particle size increases. Percentages of ash content of 13.71, 13.49, and 9.5 are found in 40, 60, and 80

† If the fuel is briqquete or charcoal then
$E_{fuel} = f_{cm} * (1 - MC) * LHV_{Briqquete\ or\ charcoal}$

mesh briquettes, respectively. Higher as content in briquettes may reduce the heating value of the briquettes. According to Indonesia standard SNI No.1/6235/2000, the maximum ash content in biomass briquettes is 8%. Thus, the briquettes with 80 mesh particle size is fulfill the SNI standard.

Similar to ash content, carbon and hydrogen content also rise as particle size steps up. The highest carbon content of 62.57 % and hydrogen content of 3.84 are obtained in briquettes with a particle size of 80 mesh. Compared with the SNI standard where maximum carbon content is 77%, the carbon content in the briquettes of 40, 60, and 80 mesh are justified. Meanwhile, sulfur content is found to be 0.22%, 0.43%, and 0.15% in the 40, 60, 80 mesh briquettes, accordingly.

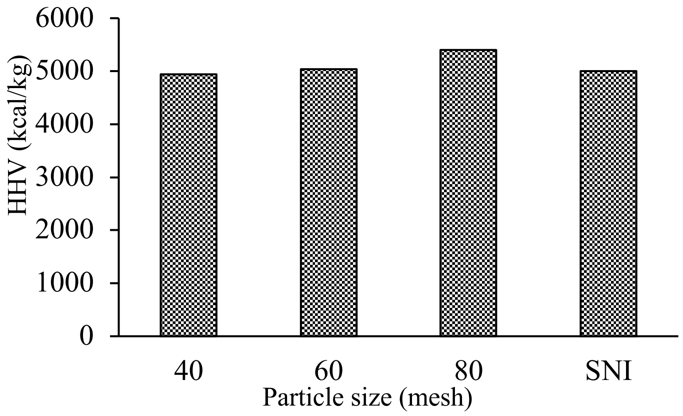
Table 3. Result of proximate and ultimate analysis of

Proximate analysis parameters	Particle size		
	40 Mesh	**60 Mesh**	**80 Mesh**
Ash (%)	12.12	11.18	8.58
Moisture content (%)	12.59	11.34	8.09
Volatile matter (%)	16.88	17.08	25.31
Fixed carbon (%)	61.42	60.41	58.12
High heating value (kcal/kg)	5350.83	5334.51	5860.68
Lower heating value (kcal/kg)	4676.78	4729.19	5386.40
Ultimate analysis parameters	**Particle size**		
	40 Mesh	**60 Mesh**	**80 Mesh**
S (%)	0.22	0.43	0.15
C (%)	60.69	60.31	62.57
H (%)	2.82	3.11	3.84
N (%)	1.15	0.98	1.15
O (%)	21.41	21.68	22.79

charcoal briquette from jackfruit peel

The HHV of the briquettes are shown in Fig. 5. The results are compared with the recommended HHV in the SNI Standard. The HHV enhances as particle size increases from 40 mesh to 60 mesh. The enhancement is due to higher carbon and hydrogen content in larger particle size briquettes. This indicates that the HHV is highly dependent on the composition of carbon and hydrogen in the briquettes. From Fig. 5, it can be observed that briquettes with a particle size of 60 and 80 mesh justify the SNI standard. The values are 5038 kcal/kg for 60 mesh briquettes and 5404 kcal/kg for 80 mesh briquettes. These values are higher than the SNI value, i.e., 5000 kcal/kg.

Once the composition of H, moisture content, and HHV of each briquette are obtained from the proximate and ultimate analysis, the lower heating value (LHV) is examined (Tabel 3) based on equation (1). The LHV value for 80 mesh samples is the greatest when compared to 60 and 40 mesh samples. This is because the 80 mesh sample has the highest HHV and hydrogen (H) values, this sample also has the lowest water content of 8.09% when compared to the 60 mesh (11.34%) and 40 mesh (12.59%) samples. Based on the ratio of LHV to HHV where for samples 40, 60, and 80 mesh



are 0.87, 0.87, and 0.92 respectively, it shows that briquette with 80 mesh charcoal is the most feasible to be used as fuel in micro gasification furnace in Mbarek *gudeg* center if compared to briquette 40 and 60 mesh samples.

Fig. 5. The high heating value of charcoal briquette from jackfruit peel and its comparison to National Indonesian Standard (SNI) for Briquette production

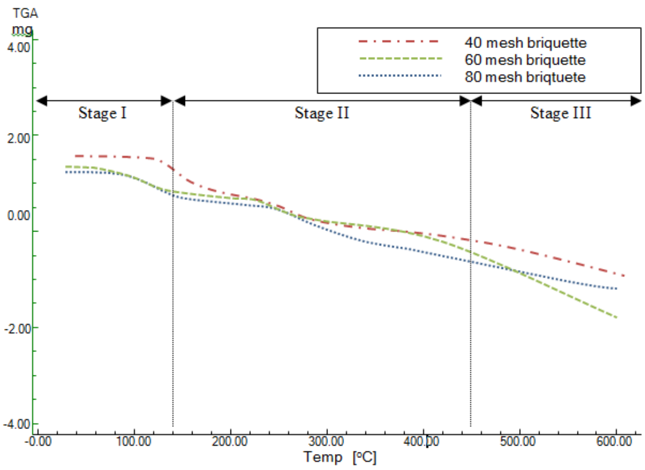


Fig. 6. Mass loss of the briquettes using TGA

Combustion characteristic in terms of mass loss during combustion is investigated using thermos-gravimetric analysis and the result is depicted in Fig. 6. The nature of TGA analysis gives information on thermal degradation through three stages [34], which is stage I, II, and III. From Fig. 6, mass loss occurs up to the temperature of 120°C, between 120°C to 450°C, and above 450°C at stage I, stage II, and stage III, respectively. The mass-loss rate of 40 mesh briquettes is slower than the mass loss rate of 60 mesh as well as 80 mesh briquettes, particularly in stage I and III. This is due to better interparticle bonding in briquettes 40 mesh. In stage II, mass-loss rates of the three briquettes size are almost similar. Meanwhile, during stage III, the fastest mass loss occurs in 60 mesh briquettes followed by 80 mesh briquettes and the slowest occurs in 40 mesh briquettes.

3.3 Thermal Efficiency of Fuel

Based on the thermal efficiency test data of jackfruit leather waste briquettes using 80 mesh of charcoal powder, showing thermal efficiency of 13.40%. When compared to other fuels according to the existing conditions of fuel types in the Mbarek *gudeg* center where the value of thermal efficiency for regular charcoal and wood are respectively 10.18% and 22.70%, then the thermal efficiency for jackfruit peel briquettes is the greatest (Fig. 7). As a comparison, a thermal efficiency test for LPG gas that is commonly used for the cooking process of most people in Yogyakarta is also done. The efficiency of this LPG is still higher when compared to other fuels, which is equal to 45.41%.

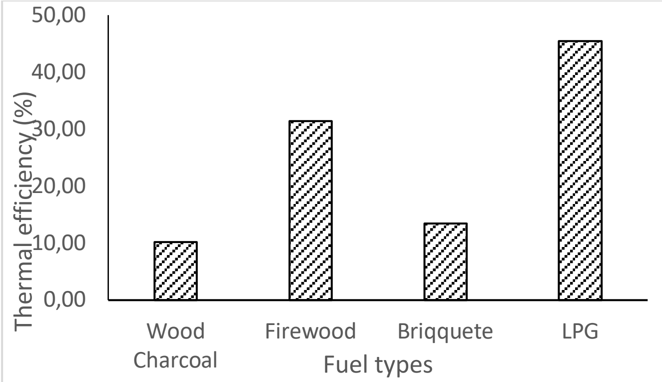


Fig. 7. Thermal efficiency of biomass fuel variations using a micro gasification furnace and its comparison with LPG gas

Table 4. Fuel replacement potential calculation based on ERP value and thermal efficiency

Parameters	**Code and formula**	***Gudeg* restaurant names**		
		***Gudeg* Haji Ahmad**	***Gudeg* Bu Lis**	***Gudeg* Bu Is**
A. Raw material (jakfruit peel)				
Fuel type (Existing)	(1)	wood	charcoal	wood
Total mass (kg)	(2)	61.80	76.20	10.30
LHV(kcal/kg)	(3)	3,821.00	6,688.00	3,821.00
ERP (kcal)	(4)=(2)*(3)	236,137.80	509,625.60	39,356.30
Thermal efficiency (%)	(5)	22.70	10.18	22.70
Net Energy (kcal)	(6)=((4)*(5))/100	53,603.28	51,900.93	8,933.88
B. Charcoal briquette of jackfruit peel				
Waste generation (kg/day)	(7)	41.42	20.71	4.14
Briquette mass (kg/day)‡	(8)=(7)*25.82%	10.69	5.35	1.07
LHV (kcal/kg)	(9)	5386.40	5386.40	5386.40
ERP (kcal)	(10)=(8)*(9)	57,604.46	28,802.23	5,760.45
Thermal efficiency (%)	(11)	13.40	13.40	13.40
Net Energy (kcal)	(12)=(10)*(11)/100	7,719.00	3,859.50	771.90
Fuel replacement potential (%)	(13)=(12)*(6)/100	14.40	7.44	8.64

‡ the value of 25.82% is the multiplier factor to calculate the mass of the charcoal yield in the slow pyrolysis process based on the research of Ma'arif, et al.[29]

From the calculation of fuel replacement potential of existing fuel to charcoal briquette of jackfruit peel in Table 4, this waste-to-energy system is able to replace the average amount of fuel by an average of 10.16%. This shows that this briquette fuel able to replace wood charcoal fuel and firewood with almost equivalent performance for cooking *gudeg*. In addition, based on the energy possessed by the fuel shows that the higher the LHV value, the higher the thermal efficiency value obtained.

4. Conclusion

It can be concluded that particle size impacts on HHV and combustion characteristic of charcoal briquettes. Regarding the SNI standard No 1/6235/2000, briquettes with 80 mesh particle size are the best in present work. Ash content, carbon content, and HHV of 80 mesh briquettes justify the SNI standard. Based on calculation data of fuel replacement potential although briquette products are only able to replace existing fuel used for cooking *gudeg* at an average of 10.16%, but this product in terms of thermal efficiency for cooking warm food so that the jackfruit skin waste produced can be used independently and not add to the burden of waste generation in landfills. Further research is needed related to pyrolysis technology that is more effective for processing this raw material so that the heating value can be increased, and the operational time of briquette making can be faster.

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