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Research article

Characterization of charcoal briquettes produced from blending rice straw and banana peel

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ABSTRACT

Blending rice straw and banana peel to form briquettes pronounced their properties. The addition of banana peel resulted in high physical and combustion properties. Different briquette samples were procured by blending varying the loads of rice straw and banana peel at the ratios of 100:0, 90:10, 80:20, 70:30, 60:40, 50:50, 40:60, 30:70 20:80, 10:90, and 0:100, respectively, using cassava starch as the binder. The properties of the sample briquettes were investigated, and it was noted that the physical properties of briquettes produced using rice straw and banana peel at the ratios of 30:70, 20:80, and 10:90 had high bulk density of 610–660 kg/m^3 and compressed density of 768–831 kg/m^3. The combustion properties of low moisture and ash content were approximately 9.7%–10.6% and 16.5%–18.2%, respectively; volatile matter was 39.7%–44.0%; fixed carbon was 28.9%–32.4%; and high heating value was 20.98–21.26 MJ/kg. Residual waste from Community Enterprise of Crispy Banana Chips was used for the production of more effective briquettes and as a natural alternative fuel to expand the global eco-friendly charcoal briquette market.

1. Introduction

The consumption of fuel is increasing rapidly globally. Therefore, alternative energy sources with features such as convenient sourcing, ease of preparation, and having various applications are required. In particular, production of energy from biomass materials is studied in many countries globally, such as England, Europe (Germany and France), China, Brazil, Africa, and Thailand. Fuel produced from biomass materials has many uses, and the trend for utilizing charcoal briquettes is increasingly observed in the African continent as well as in many Asian countries. The global application of charcoal briquettes, which is an eco-friendly energy source, was primarily for barbecue and in households for cooking and heating [1]. Fuels can be obtained from renewable energy sources, such as forests, wood, agricultural waste, and food waste. Fuel from forest and wood has high density and caloric value but is expensive, yields fire bursts, is unsustainable, and has greenhouse effect. Therefore, an alternative energy using charcoal briquettes was required to replace forest and wood. The production of charcoal briquettes is possible from agricultural residues, such as coffee husks [2], rice straw, sugarcane leaves [3], and palm kernel shells [4]. Renewable energy from biomass is mostly economical and simple and can be used to produce charcoal briquettes from efficient agricultural residues. The disadvantages of using charcoal briquettes made from agricultural residue are low density and caloric value (high heating value) and high moisture and ash content. However, charcoal briquettes prepared from single starting materials have low density and calorific value. Previous studies have suggested some

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agricultural residues such as banana leaves (17.70 MJ/kg) [5], bagasse (18.35 MJ/kg) [6], hazelnut shell (18.89 MJ/kg) [7], and rice straw (16.13 MJ/kg) [8] to form charcoal briquettes. Rice straw, which is a large agricultural waste, can be used as an alternative fuel to replace the use of wood firewood. In Asia, the amount of rice straw is approximately 503 million tones [9]. A huge bulk of rice straw is used for bioethanol production every year [10,11], but a substantial amount is still left unused. In this regard, studies in South Asia noted these problems: (1) unvalued rice straw and unstable price and (2) all farmers burn rice straw in the field for cultivation in the next cycle. This open burning is very problematic as it negatively affects global warming. Avoiding open field burning in Asia can help reduce global warming by decreasing carbon dioxide emissions and 322 metric tons of carbon dioxide equivalents ($MTCO_{2e}$) annually [12]. An alternative to mitigate this problem is that the rice straw must be converted to fuel, such as charcoal briquettes. From assessing the potential of charcoal from rice straw, it was found that there was a calorific value and fine particle [13] that could be developed into inter-particle by solid bridge in briquettes using cold pressing. However, briquettes produced using rice straws have low density because the fine particles of rice straw lead to higher smoke formation [14], low caloric value, and high moisture and ash content. This can be circumvented by combining several materials to form briquettes to increase briquette strength compared with single material briquettes. Previous research studies found that briquettes from bean straw:maize cob have ash content of 4.5%, volatile matter (VM) content of 77.5%, fixed carbon (FC) of 18.0%, and calorific value of 17.9 MJ/kg [15]; rice straw:sugarcane leaves briquettes have moisture content (MC) of 4.22%, high calorific value of 17.83 MJ/kg, and low ash content of 9.07% [3]; briquettes from coffee husks and groundnut shells at ratio of 30:70 have high calorific value of 22 MJ/kg [16]; and vegetable market waste and sawdust ratio (at a ratio of 25:75) briquettes have MC of 4.4%, VM of 83.2%, ash content of 2.1%, FC of 10.3%, and calorific value of 15.72 MJ/kg [17]. However, the amount of rice straw available is insufficient to produce charcoal briquettes for the whole year. Therefore, banana peels were considered another option as a huge amount of banana peels are generated globally. The average in 2019 worldwide production of bananas is 116 million tonnes per year, and India is the largest banana producer in the world producing 30.4 million tonnes per year, followed by China at 11.9 million tonnes per year. Indonesia produced 7.2 million tonnes, Brazil produced 6.8 million tonnes, and Colombia produced 2.9 million tonnes per year. Thailand has a production capacity of 1.2 million tonnes per year and is ranked 6th in the world [18], which results in a huge amount of banana peel waste. This waste has a calorific value of 18.89 MJ/kg [19], and banana peels can be used as an alternative energy source for the production of briquettes. Charcoal briquettes from rice straw and banana peel, which are agriculture residues, can replace wood and forest.

This research aimed to obtain an alternative energy source from agriculture residue for energy production. The energy potential and production of charcoal briquettes from rice straw and banana peel were investigated. The effect of blending rice straw and banana peel at different ratios on the increase physical properties of briquettes were also investigated. Moreover, the characteristics and properties of the varying ratios was determined though physical, proximate, elemental chemicals analyses, and high heating value (caloric value).

2. Materials and methods

2.1. Materials

Rice straws were obtained from the crop harvested in Northeast Thailand between December to February in 2021. Banana peels residue was obtained from Community Enterprise of Crispy Banana Chips, Non Suwan Districts, Buriram Province. Both initial materials were dried in direct sunlight in the open air for 14 days [20] before further experiments to reduce moisture and for carbonization.

2.1.1. Carbonization

Carbonization of rice straw and banana peel was done following a previous study [21]. In brief, carbonization was performed in kiln metallic containers with volume of 200 L, height of 89 cm, and inner diameter of 56 cm; the kilns were covered by a 2.5 cm thick layer of alumina and silica insulation. All the observations, including quantity used, duration, final portion, and smoke emission color changes were noted for 24 h until cool. During the carbonization process, the holes were covered with mud to avoid the amount of air available for complete combustion in the carbonizer as agricultural residue was used. The kiln apparatus used in this study is illustrated in Fig. 1 (a, b). After carbonization for one day, the kiln was allowed to cool until it was safe to let it come in contact with open air. After

(a) (b)

Fig. 1. Metal kiln. (a) Internal design and (b) during carbonization.

the kiln cooled, the charcoal was harvested and ground to a fine powder. The starting agricultural residue and charcoals after the carbonization are illustrated in Fig. 2(a–f). The preliminary materials for densification were determined by ultimate analysis (CHNS/O Analyzer; Thermo Scientific FLASH-2000), proximate analysis (MC, ash, FC, and VM), and calorific or high heating value (HHV).

2.2. Densification

The preliminary charcoal to form briquette was made from rice straw and banana peel at ratios of 100:0, 90:10, 80:20, 70:30, 60:40, 50:50, 40:60, 30:70 20:80, 10:90, and 0:100 denoted with sample IDs of RB1, RB2, RB3, RB4, RB5, RB6, RB7, RB8, RB9, RB10, and RB11, respectively. The compositions were mixed with cassava starch binder at 6% (wt/wt) and 5% (wt/wt) of binder in all briquette ratios. In addition, the combinations contained approximately 200 mL of water. The combinations of binder were poured in a metallic mold, a hollow cylinder with inner diameter of 4 cm, length of 6.5 cm and with a middle hole of 0.5 cm (Fig. 3). The effect of rice straw mixed with banana peel on briquetting properties was determined. Five ratios were selected to be used in succeeding test as shown in Table 2. The five briquettes were dried in the sun for seven days [22] prior to analysis and characterization.

2.3. Charcoal briquette characterization

2.3.1. Physical and mechanical properties

Bulk density (kg/m^3) of the charcoal briquettes was studied according to procedures of ASTM D5057-10 by determining the relation between sample mass and volume. The shatter index was determined following ASTM-D3038. The charcoal briquettes were tested for compressed density using Eq. (1) [23]. The analyses were performed in triplicate. Subsequently, ejection from the molding cylinder was measured as the ratio of measured mass (kg) by calculated volume (m^3). The weight was obtained using a digital balance (Sunford; FGH 5000). The height and diameter were determined using a digital Vernier caliper (hardened stainless steel).

$$D_{co} = W_{ej} / \left(\pi h r^2\right) \left(kg / m^3\right) \tag{1}$$

2.3.2. Proximate analysis and calorific value

MC (according to ASTM-D3173-03), ash content (ASTM-D3173-04), VM content (according to ASTM-D3175-02), and FC content (according to ASTM-D3172-07) of the fuels were determined. The analyses were performed in triplicate. The calorific value or HHV was determined using an automatic bomb calorimeter (Leco model AC-500), which followed the procedures of ASTM-D5865. The analyses were performed in duplicate.

2.3.3. Burn out time and combustion test

The burn out time for the fuels to burn was recorded using a stopwatch [24]. The combustion test was performed by boiling water (water boiling test) using materials and traditional tripod stoves in a typical rural household to simulate normal cooking conditions. The experiment was replicated three times, and mean values were noted. Twenty milliliters of water at an initial temperature of 30 °C was filled in a cooking pot (diameter 18 cm and capacity 2.1 L). Then, three briquettes weighing approximately 183 g were placed in the cooking oven (Fig. 4a and b). The briquettes were ignited (Fig. 4a) after being speckled, and burn out time until ash was obtained was recorded (Fig. 5). During this test, other fuel properties of the briquettes, i.e., burning rate and specific fuel consumption, were also determined [25]. Furthermore, the level of smoke formation was observed. The burning rate is the ratio of the mass of the fuel burnt (in

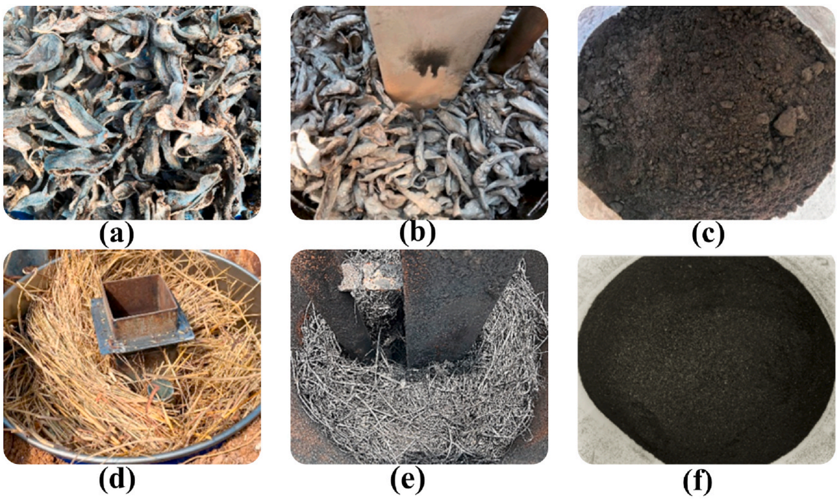


Fig. 2. Agricultural residue. (a) dried banana peel; (d) dried rice straw; (b) and (e) banana peel and rice straw, respectively, after carbonization; (c) fine charcoal from banana peel; (f) fine charcoal from rice straw.

Fig. 3. Compaction apparatus.

Table 1
Proximate, ultimate, and HHV characteristics of starting charcoal.

Starting charcoal	Proximate analysis				Ultimate analysis				HHV (MJ/kg)
	Ash (%)	VM (%)	FC (%)	MC (%)	C (%)	H (%)	N (%)	S (%)	
Rice straw	31.9	14.7	46.9	6.5	52.68 ± 0.36	1.89 ± 0.01	0.92 ± 0.03	0.00 ± 0.00	19.13 ± 0.04
Banana peel	17.2	30.5	41.1	11.2	53.83 ± 0.38	5.07 ± 0.18	1.21 ± 0.02	0.00 ± 0.00	22.00 ± 0.25

grams) to the total time taken (in minutes) consuming Eq. (2).

$$\text{Burning rate} = \frac{\text{mass of fuel consumed (g)}}{\text{total time taken (min)}} \tag{2}$$

The specific fuel consumption indicates the ratio of the mass of fuel consumed (in grams) to the quantity of boiling water (in liters) consuming Eq. (3).

$$\text{Specific fuel consumption} = \frac{\text{mass of fuel consumed (g)}}{\text{total mass of boiling water (Liter)}} \tag{3}$$

3. Results and discussion

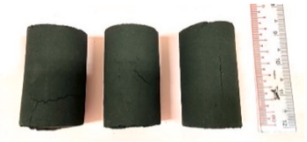
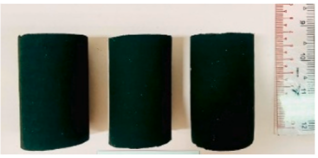
3.1. Characterization of the starting charcoal

Carbonization process [26,27] as follows that the first stage at 20–180 °C, will be volatilized moisture, and then increase temperature at 180–270 °C will be decomposition the structures of hemicellulose, lignin, cellulose, and some organic compounds (protein, and fat) in starting materials. When the temperature still be 270–400 °C, result found that break bounding in the lignin, hemicellulose, cellulose and remains little residual nitrogen from incomplete some organic compounds. Addition, the carbonization increased to approximately 400–500 °C, which are some organic matters and volatiles for carbon dioxide, methane, carbon monoxide, then result that deposit of carbon [28]. Resulting in the machine not being able to measure (detected), so the purpose of analyzing charcoal formed from oxygen-free combustion want to confirm the result that the starting material is burnt into charcoal from carbon content and is related to the constant carbon content as shown in Table 1. This result was corresponding to Pathak et al. [29], reported that high temperature affecting to stable FC. FC in the charcoal briquettes from rice straw and banana peel was approximately 46.9% and 41.1%, respectively, MC was 6.5% and 11.2%, ash content was 31.9% and 17.2%, and VM was 14.7% and 30.5%, respectively as presented in Table 1. However, charcoal from carbonization had a higher HHV and was approximately 22.00 ± 0.25 MJ/kg for banana peel and 19.13 ± 0.04 MJ/kg for rice straw. This determined higher HHV corresponded to high VM and elemental carbon. The accepted value of VM content from agriculture wastes is <40% to improve the properties of the briquette [30]. However, previously studied preparations of briquettes, such as those from biomass, low grade iron ore [31], coal briquette [32], and naturally grown algae [33], analyzed a variety of raw materials and their high VM and high calorific value. The results showed high FC but low moisture and VM. During carbonization, volatiles were noted as temperature increased, and different elemental carbon were observed by ultimate analysis. High FC and synonymous carbon elements were observed by ultimate analysis.

3.2. Primary screening of densification

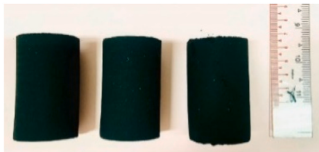
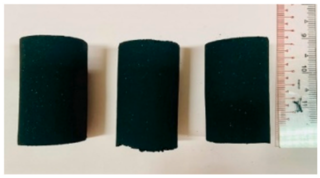
Table 2 shows that for the sample ID RB1, RB2, RB3, and RB4 with starting materials of rice straw and banana peel at ratios of 100:0, 90:10, 80:20, 70:30, and 60:40, it was difficult to compact both materials, resulting in difficulty in formation in the mold

Table 2
Forming and maintaining shape ability of charcoal briquettes made from varying ratios of rice straw and banana peel.

Ratio of charcoal (%wt)		Sample ID	Forming ability			Ability to maintain shape
Rice straw	Banana peel		Easy forming	Difficult forming	No forming	
100	0	RB1	No	Yes	Yes	
90	10	RB2	No	Yes	Yes	
80	20	RB3	No	Yes	Yes	
70	30	RB4	No	Yes	Yes	
60	40	RB5	No	Yes	Yes	
50	50	RB6	Yes	No	No	
40	60	RB7	Yes	No	No	
30	70	RB8	Yes	No	No	

(*continued on next page*)

Table 2 (*continued*)

Ratio of charcoal (%wt)		Sample ID	Forming ability			Ability to maintain shape
Rice straw	Banana peel		Easy forming	Difficult forming	No forming	
20	80	RB9	Yes	No	No	
10	90	RB10	Yes	No	No	
0	100	RB11	Yes	No	No	

(a) (b)

Fig. 4. (a) Ignited briquettes and (b) burning duration.

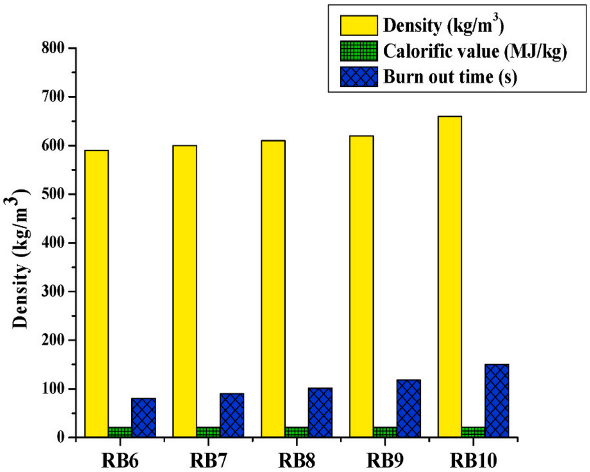


Fig. 5. Density and HHV affect to burn out time briquette.

cylinder. However, when the amount of rice straw was increased, fine particles which have high surface area increased; the rice straw adsorbed high amounts of water and remained hydrated due to the compression force of the charcoal briquette tool. This caused friction, and the charcoal was firmly attached to the apparatus, thus, making it impossible to compress the forming. In addition, increased amounts of banana peel in sample ID RB5, RB6, RB7, RB8, RB9, and RB10 at ratio of 50:50, 40:60, 30:70, 20:80, 10:90, and 0:100 resulted in compact briquettes with a smooth and homogeneous surface. Therefore, mixing ratios of 50:50, 40:60, 30:70, 20:80, 10:90 by weight were selected to produce the briquette fuel for the next test as the mixture was easy to compact at this ratio and owing to the relatively horizontal surface of the resulting briquettes (Table 2). Briquettes produced from these ratios were subjected to physical and combustion characterization and appropriateness of the quality fuel.

3.3. Physical characterization

The physical properties of the starting material are presented in Table 3. Density is an important property that directly relates to the energy to volume ratio of briquettes [34] and is important in determining the management, transportation (decreasing logistic expenses), ignition, and combustion characteristics [35]. The extent of this impact is feedstock and particle-dependent. In this study, the density ranged from 590 to 660 kg/m^3. Density increased with increasing banana peel amount. Best results were obtained when using the fine particle of rice straw and coarse banana charcoals, resulting in excellent compaction and densification. The effect of densification by using cold pressing and at room temperature in density property was detected from different starting materials. The average drop shatter test for all ratios was 1.00 ± 0.00. The high density of briquettes at all ratios of rice straw and banana peel charcoals showed indifferent drop shatter test results. The mean compressed density of the briquettes generally increased from 659.0 to 831.63 kg/m^3 as the blending ratio increase from 50:50, 40:60, 30:70, 20:80, 10:90, with increased banana peel amount. The banana peel and rice straw of charcoal have a high nitrogen as shown in Table 1, which are residue nitrogen atom from lignin ($C_{18}H_{13}N_3Na_2O_8S_2$) [36]. This residue of natural binder from lignin and hemicellulose can be binding components in briquette [37]. Thus, the increasing the amount of banana peels charcoal, it increases the nitrogen content was result that the densification and different of starting material particles affecting to inter-particle binding solid bridges in mixing briquette, which are increasing density. The highest compressed density was observed at the ratio of 10:90 (RB10) and lowest was observed at the ratio of 50:50 (RB6). This suggested that the effect of the increased amount of banana peel was more important on the compressed density. Hence, the effect of different starting materials on the different properties of briquettes was studied. From the research of bending different raw materials, it has been reported that straw:maize cob in ratio of 75:25, 50:50, and 25:75 was found that high density range of 1018.4–1151.2 kg/m^3 [14]. Therefore, this research corresponded to prepare briquettes containing 80% by weight molasses at different charcoal/molasses ratios of 40:60, 30:70, and 20:80 to study the various characteristics in terms of bulk density [38].

3.4. Combustion characterization

Table 4 shows MC of the various ratios of charcoal briquette. MC increased with increased percentage of banana peel in the briquettes and ranged from 8.6% to 10.6%, with the accepted limit of MC for high standard briquettes being 15% [39]. MC was analyzed to determine the ability of ignition. Consequently, this property should be as low as possible because high MC indicates difficulty when burning as it would require more energy for combustion and would result in dark smoke. VM from briquette charcoal were elemental carbon, hydrogen, and oxygen. The ratios of starting material of charcoals had an important affect on the determined VM. However, the highest value of VM from banana peel charcoal was 44.0% and the least from rice straw was 14.7%. The amount of banana peel was increased in mixing ratios of briquettes, which led to a high percentage of VM. The percentage of VM in the current briquettes was higher than that in common biomass and biomass briquettes, such as rice husk and starch (34.38%) [40]. However, these results showed that the composite briquette had VM content values comparable to firewood (75%–80%) [41] and was higher than conventional fuel sources, such as lignite (43.5%) [42], bituminous coal (25.95%) [43], and coal (20%–35%) [44]. From these results, it was found that VM was a important factor to evaluate the suitability of charcoal briquette. The ideal properties of charcoal briquettes are high VM because they would burn readily and are easy to ignite during combustion. In this study, increasing banana peel amount in mixing briquette charcoal increased VM content and reduced FC contents but increased HHV, The HHV of bending starting material results showed that range of 20.20–21.26 MJ/kg. Therefore, the research found that increasing the banana peel of charcoal had a higher HHV than the pure rice straw of charcoal and, which was comparable with that of agriculture waste, such as palm kernel shells (18.72 MJ/kg) [4], straw:maize cob (17.9 MJ/kg) [14], wheat straw (16.27 MJ/kg), palm fiber (16.84 MJ/kg), and rice straw (16.13 MJ/kg) [45], and banana leaves (17.70 MJ/kg) [46]. Then, banana peels are used as an ingredient in the production of briquettes

Table 3
Physical properties of charcoal briquette with different ratio of rice straw and banana peel.

Sample ID	Physical properties		
	Bulk density (kg/m^3)	Compressed density (kg/m^3)	Drop shatter test
RB6	590 ± 0.01	659.0 ± 20.10	1.00 ± 0.00
RB7	600 ± 0.02	721.73 ± 24.55	1.00 ± 0.00
RB8	610 ± 0.00	768.56 ± 13.52	1.00 ± 0.00
RB9	620 ± 0.07	779.07 ± 15.16	1.00 ± 0.00
RB10	660 ± 0.01	831.63 ± 14.35	1.00 ± 0.00

Table 4
Proximate analysis and calorific value.

Sample ID	Proximate analysis				HHV (MJ/kg)
	MC (%)	VM (%)	FC (%)	Ash (%)	
RB6	8.6	31.9	37.0	22.5	20.20 ± 0.04
RB7	9.2	34.1	35.4	21.3	20.73 ± 0.17
RB8	9.7	39.7	32.4	18.2	20.98 ± 0.03
RB9	10.5	41.0	31.4	17.1	21.00 ± 0.31
RB10	10.6	44.0	28.9	16.5	21.26 ± 0.41

mixed with rice straw charcoal. It was found that the HHV was acceptable according to the standard criteria [47]. The suitable that charcoal from rice straw is a pollution problem and is not found throughout the year. This indicates that using the same amount of fuel, more energy can be generated from the blend. Ash is an inorganic matter and is residue that does not undergo combustion and results in calcium oxide and magnesium oxide silica. The percentage of ash decreased as banana peel content increased. The ash content ranged from 16.5% to 22.5%. The lowest percentage of 16.5% was found in sample RB10, which was rice straw and banana peel charcoal at the ratio of 10:90. These observations suggest that the lowest ash content in fuel briquette has higher HHV. However, the percentage of ash was affected by starting materials of charcoal and densification post the production technique.

3.5. Burn out time and combustion test

Burn out time are predominant of briquette and related to density, which are physical property. However, the blending ratio of starting materials and different particle was found increase density affecting to decrease porosity as compaction of briquette [14,48]. Burn out time was determined for boiling water to explain why sample RB10 (21.26 MJ/kg) had higher burn-out time than sample RB6–RB9 (20.20–21.00 MJ/kg). In addition, density affected burn-out time, suggesting that compressed density of sample RB10 (660 ± 0.01 kg/m^3) increased to approximately 831.63 ± 14.35 kg/m^3. However, it was obvious that the briquette containing higher banana peel amount showed higher density and HHV, thus, leading to longer burn-out time (Fig. 5). This result corresponded to the high densities affecting increased HHV for quality fuel [32,46]. Testing different ratios demonstrated that burning rate decreased because banana peel absorbed high amount of water, affecting MC. Decreased burning rate corresponded to high VM, resulting in rapid ignition and burn out. The current briquette is advantageous as fuel is conserved and burn-out time was longer, which was evidenced by the combustion test (Fig. 6a). The high burning rate was effect to consumption fuel and then, the fuel burns out rapidly, which corresponds to the duration of burn-out time as shown in Figs. 5 and 6a. This main effect of the natural thermal resistance was that the combustion of banana peel-containing briquette increasingly retarded with time, thus, reducing the burning rates of these particular briquettes during combustion [14,49]. This means that such briquettes will be able to burn at slower rates over-time. Moreover, this resulted in differences in briquette density and HHV. The specific fuel consumption value of the briquettes was 3.50–3.69 g/L. The findings were revealed that bending rice straw and banana peel of charcoal recorded fairly stable specific fuel consumption. An increase in banana peel contents in briquettes reduced burning rate but did not affect specific fuel consumption and increased burn-out time (Figs. 6b and 5). This research similar to the findings of this research [14]. It has been hither to suggested that briquette produced from rice husk, sawdust and corn cob. These was comparable to the findings of [50], reported the bending of coffee husk and coco peat, which presented that coffee husk briquettes had burning rate 6.611 g/min (specific fuel consumption, 0.212 kg/L), coco peat briquettes had burning rate 8.631 g/min (specific fuel consumption, 0.216 kg/L), and coffee husk and coco peat ratio of 50:50 had burning rate 8.591 g/min (specific fuel consumption, 0.292 kg/L).

4. Conclusion

This research was conducted to evaluate charcoal briquettes produced using rice straw and banana peel at different ratios. The results showed that increasing banana peels affected its physical properties and increased density and high compressed density, but decreased ash content. Furthermore, high calorific value, high VM, and low FC content within standard values were noted. The ratio of RB8 yielded low ash content, low MC, high FC contents, high VM, and HHV. The combustion properties of the difference ratio of from rice straw and banana peel showed long burn out time, decreased burning rate, and specific fuel consumption of approximated average of 3.50 g/L. Thus, starting materials from agriculture residues and a simple production method were used to establish an alternative fuel.

Author contribution statement

Sakesit Duangkham: Performed the experiments; Contributed reagents, materials, analysis tools or data; Wrote the paper.

Pattaranun Thuadaij: Conceived and designed the experiments; Performed the experiments; Analyzed and interpreted the data; Contributed reagents, materials, analysis tools or data; Wrote the paper.

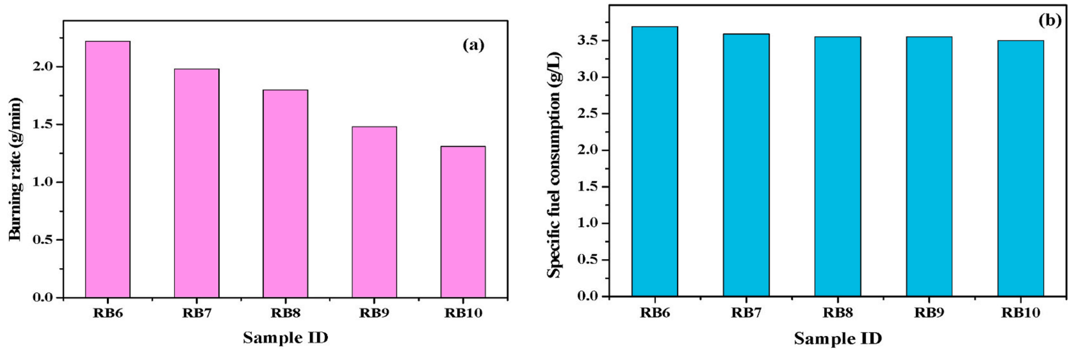


Fig. 6. Burning rate (a) and specific fuel consumption (b) for various briquettes.

Data availability statement

Data included in article/supp. material/referenced in article.

Additional information

No additional information is available for this paper.

Declaration of competing interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

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