Materials Physics and Mechanics. 2022;50(1): 20-36
Research article
http://dx.doi.org/10.18149/MPM.5012022_2

Submitted: January 23, 2021
Approved: August 16, 2022
Accepted: August 16, 2022

Physicochemical and mechanical properties of briquettes prepared from the combination of micrometer-sized areca nutshell, tofu dreg, and citronella: from the literature review to experiments

A.B.D. Nandiyanto[✉]**, S.N. Hofifah, S. Anggraeni, N.Z. Latifah, J.E. Sitanggang, O. Sopian, Z. Saputra**

Fakultas Pendidikan Matematika dan Ilmu Pengetahuan Alam, Universitas Pendidikan Indonesia,

Jl. Dr. Setiabudi No. 229, Bandung, Indonesia

✉ nandiyanto@upi.edu

Abstract. Effects of the particle size (i.e. 100, 150, and 500 μm) and composition of biomass on physicochemical and mechanical properties of briquettes were evaluated. This study used biomass from the mixture of tofu dreg (TD), areca nutshell (ANS), and citronella (CN). This study was also completed with a literature review. ANS was carbonized at 250°C for 2 hours. Then, all raw materials (i.e. TD, ANS, and CN) were dried, saw-milled, and mixed with tapioca starch as a binder to form a dough. The particle size and ANS composition gave an impact on the briquettes' performance, including burning rate, specific fuel consumption, and mechanical properties. Particle size influenced the compact component in the briquette. ANS affected carbon and moisture contents in the briquette, improving its compressive strength. This study demonstrates the alternative solution for reducing organic wastes by converting them into briquettes.

Keywords: briquettes, biomass, energy, mechanical properties, tofu dreg, areca nutshell, citronella

Acknowledgements. *This study acknowledged RISTEK BRIN for Grant-in-aid Penelitian Terapan Unggulan Perguruan Tinggi (PTUPT).*

Citation: Nandiyanto ABD, Hofifah SN, Anggraeni S, Latifah NZ, Sitanggang JE, Sopian O, Saputra Z. Physicochemical and mechanical properties of briquettes prepared from the combination of micrometer-sized areca nutshell, tofu dreg, and citronella: from the literature review to experiments. *Materials Physics and Mechanics*. 2022;50(1): 20-36. DOI: 10.18149/MPM.5012022_2.

1. Introduction

Bio briquettes are solid fuels made from a mixture of biomass. Biomass is a term used to describe all types of organic materials that are the results of the photosynthesis process [1]. In Indonesia, biomass is largely abundant, while its usage is not optimal yet [2].

Reports on the use of biomass as alternative energy are well-documented. Many strategies have been reported, and the results were compared to the briquette standard [3].

Publisher: Peter the Great St. Petersburg Polytechnic University

Detailed current research for the use of briquette from biomass is presented in Table 1. However, studies on the effects of the particle size of raw materials on the briquettes' quality are typically unconcerned.

Table 1. The previous research on the preparation of briquettes from biomass

No	Biomass	Binder	Results	Ref.
1	Water hyacinth (*Eichhornia crassipes*) charcoal	Molasses	The molasses to charcoal ratio had an impact on the briquettes' quality and characteristics. With increasing amounts of binder, ash content decreased while volatile combustible matter and fixed carbon increased. The highest calorific value (16.6 MJ/kg) and compressive strength (19.1 kg/cm^2) were produced by the 30:70 charcoal/molasses ratio. The potential for turning water hyacinth into an alternative fuel source has been demonstrated by the results.	[4]
2	Areca leaves	Wheat flour	According to IS1448-7 standards, the areca leaves' gross calorific value was determined. According to the analysis, compared to briquettes with particle sizes larger than 1700 µm, 600 and 425 µm of areca leaves components are better. Further, briquettes with 85-µm areca leaves have the highest calories at 14.57 MJ/kg. The briquette's physicochemical properties showed low moisture content (8.08%) and low ash content (1.47%). Because they contain less nitrogen (0.61%) and sulfur (0.65%), the briquettes are environmentally friendly. As a result, producing briquettes from 850-µm areca leaves with sawdust as an additive can result in high-quality biomass fuel for use in both homes and businesses.	[5]
3	Carbonized rice husk and jatropha seed waste	Newspaper waste pulp	The briquettes with the highest heat energy content (5,650 cal/g) are those with 8% of newspaper waste pulp adhesives. The best-mixed charcoal briquettes are made from rice husk charcoal and jatropha seed at a 50:50 ratio with 8% newspaper waste pulp added as an adhesive agent. Adding more adhesive will reduce the calorific value. The best properties of mixed charcoal briquette (made from rice husk and jatropha seed waste) are moisture content of 3.85%, volatile matter of 43.87%, ash of 23.78%, fixed carbon of 28.50%, and calorific value of 5,650 cal/g. The calorific value of rice husk can be increased by the addition of jatropha seed charcoal from 3,350 to 5,650 cal/g.	[6]
4	Orange peels and corn cobs	Pasty starch	According to the results, the sample can reach the highest calorific value per kilogram of	[7]

			31,886 kcal. The mixtures made up of 20% of orange peels and 80% of corn cobs have the highest calorific values and carbon contents, which are the most desirable qualities of good solid fuel. In the meantime, a briquette made of 80% orange peels and 20% corn cobs has shown some promise.	
5	Cocoa Shells and Sea Mango	Tapioca flour	Small-particle briquettes have high values for relaxed density, relaxation ratio, and percentage of durability index. However, the high density of briquettes on smaller particles made the compressed density and the percentage of moisture content low.	[8]
6	Sugarcane bagasse	-	Analysis of the fuel's parameters revealed high-quality levels of low ash content (0.97 percent) and high calorific values (18.35 MJ kg-1 for gross calorific value and 17.06 MJ kg-1 for net calorific value), which suggested the fuel was well suited for direct combustion processes. The following observations were supported by indicators of mechanical quality: bulk density of 1022 kg/m^3, compressive strength of 150 N/mm^1, and mechanical durability of 99.29%.	[9]
7	Coconut (*Cocos Nucifera*) Coir and Banana (*Musa Paradisica*) Peels	Tapioca starch	The best performance of briquettes is with 310 µm of particles with a mixture content of banana peels as much as 20% of the total weight. It has good specific fuel consumption (5.42 g/mL) and a burning rate (5.10 g/min). The briquette has a compressed density of 0.39 g/cm^3, relaxation ratio of 1.70, a relaxed density of 0.23 g/cm^3, a water resistance index of 80.14%, a moisture content of 58.55%, and a durability index of 98.92%.	[10]
8	Melinjo (*Gnetum gnemon*) Shell	Tapioca	Briquettes with 10% of tapioca (sizes of 465-1000 µm) have the best relaxation ratio values, percentage moisture content, burning rates, and specific fuel consumption. Briquettes with 50% of tapioca (sizes of 74-105 µm) have the highest compressed density, relaxed density value, durability index percentage, and water resistance index percentage.	[11]
9	Banana peels, sugarcane bagasse, coconut shells, and rattan waste	Cassava starch	Banana peels (97.98%) and sugarcane bagasse (97.98%) losses are more significant in the mass reduction (96%). High calorific values of the briquettes produced are 16.98, 30.07, 32.16, and 25.93 MJ/kg for banana peels, rattan waste, coconut shells, and sugarcane bagasse, respectively. Volatile matters are gradually lower. Ash content was 7.44-11.95%, and	[12]

			moisture content is relatively low.	
10	Rice husk and red bean skin	Tapioca starch	Small particles (74-100 µm) with a binder concentration of 50% produce briquettes of good quality. Due to the small size and large surface area of the particles, as well as the high binding agent concentration, the bonds between the particles are very strong. A 20% binder concentration produced good quality briquettes for the briquettes with large particles (500-2000 µm).	[13]
11	Durian eel (*Durio kutejensis Becc*) charcoal	Starch	The briquettes were made from durian peel charcoal by adding starch as a binder at different concentrations of 3, 4, 5, and 6% to obtain moisture content, volatile matter, ash content, and calorific value. The 3% of starch binder in the durian peel briquettes had the highest quality.	[14]
12	Cassava peels and rice husks	Tapioca starch	The small particle of biomass shows good performance in the compressed and relaxed density. The 90:10 briquette with small particles has an excellent calorific value, according to the water boiling test, burning rate, and specific fuel consumption. For briquettes with medium particles and a 50:50 ratio, a good water-resistant index was obtained. For all briquettes, the average durability index values were 98%.	[15]
13	Sawdust, rice, and coconut husks	Cassava starch	The charred briquettes' calorific value was discovered to be 24.69 MJ/kg. The use of a multi-feed gasifier stove (MFGS) resulted in briquettes burning with the highest combustion efficiency (34.7%). When briquettes were used in the MFGS in place of charcoal, there were reductions in particulate matter and carbon monoxide emissions of 14 and 80%, respectively.	[16]
14	Carbon particles from potato and yam skins	Rice waste	The best quality of the prepared briquettes was for the sample with 10% adhesive. The briquettes with 30% adhesive had the highest durability index. When using 40% adhesive, excellent compressed density and water resistance index were obtained. Briquettes with less adhesive typically have a high density, little moisture content, and long flammability.	[17]
15	Onion peels and tamarind shells	Cassava Starch	Comparatively to pine, cotton stalk, wood sawdust, municipal solid waste (MSW), and cotton straw biomass briquettes, onion peels and tamarind shells (OP-TS) have better fuel properties. Onion peels and tamarind shells were used to create briquettes with a higher	[18]

			heating value. They, therefore, made a great choice for an energy source. The briquettes' carbon content has decreased while their oxygen and hydrogen contents have increased when using OP-TS.	
16	Sawdust and rice husk carbon	Starch paste	High density (bulk, compressed, and relaxed) was produced by the high concentration of carbon rice husks (CRH) in briquettes. The compaction ratio, water resistance, durability, and relative suitability decreased with a high CRH. Sawdust and CRH can be burned cooperatively inside the briquette.	[19]
17	Bamboo Fiber and Dried Clove Leaves	Dextrin	Briquettes made of dried clove leaves and bamboo fibers with 60% have good solidity, durability, fuel consumption, and moisture content, while those at 20% have good combustion performance.	[20]
18	Coffee grounds and soybean peels	Tapioca flour	Briquettes with a ratio of (60:40) and a particle size of 250 µm have good compressed density, burning rate, and specific fuel consumption characteristics.	[21]
19	Durian peels and banana midrib	Tapioca flour	The best briquette results were when using a 70:30 ratio of durian peels and banana midrib with a carbon particle size of 250 µm, according to compressed density, relaxed density, relaxation ratio, percentage moisture content, percentage of water resistance index, water boiling test, burning rate, specific fuel consumption, and durability index.	[22]
20	Peanut shells	Tapioca flour	310-µm particles gave a good performance in the compressed density and relaxed ratio. The 582-µm particle had less moisture content and high specific fuel consumption.	[23]

Our previous studies reported the mechanical properties of materials, such as iron oxide [24], tungsten trioxide [25,26], brake pad[27], bioplastic material [28-30], and food materials [31]. We also reported several characterizations and analyses for supporting the studies [32-36]. Here, this study aims to determine the quality of the briquettes as a function of the particle size and composition of several raw materials. As models of raw materials, we used a combination of tofu dreg (TD), areca nutshell (ANS), and citronella (CN). The main reasons for the use of these raw materials are:

(i) TD as the bioproduct of the tofu industry – one of the important agro-industry in Indonesia that brings great economic impacts – is not carefully handled and treated, creating problems in the environment. Direct disposing of TD causes a bad smell since TD contains high protein content (100 g of TD contains 27 g of protein) [37].

(ii) Areca nut (*Areca catechu*) is a type of palm plant that is widely cultivated in Indonesia. Areca nuts are scattered in all regions of Indonesia. Areca nut is found in various regions of Indonesia, especially in Sumatra, Kalimantan, and Sulawesi [38]. In general, areca farmers only use areca seeds. ANS is not used and becomes waste that can pollute the environment. Areca farmers usually burn ANS to reduce buildup. Combustion that is carried out can cause air pollution. In fact, ANS and other biomass such as tofu dreg have considerable energy potential and can be used as bio briquettes.

(iii) Citronella (*Cymbopogon nardus L.*) is one of the plants that produce essential oils. Citronella is widely cultivated in Indonesia, and Indonesian land has a climate suitable for its growth[39]. The essential oil from Citronella has a bitter taste, smells good, and evaporates at room temperature without decomposition [40]. The good smell of the essential oil in citronella can be added to bio briquettes, so the briquettes can emit a good smell when baked.

In addition, ANS was used as the main carbon material, where this material was carbonized before use. The carbonization process can increase the carbon content and heating value of the prepared briquette [41,42]. Our research is important to demonstrate the alternative solution for reducing waste management since such TD, ANS, and CN were typically disposed of directly to the environment.

2. Material and method

Material preparation. Briquettes were made from a mixture of TD, ANS, and CN. All materials were obtained from Pangandaran Regency, Indonesia. The tapioca flour as the binder was obtained from Cimahi, Indonesia. The TD/ANS/CN compositions were varied in the ratio of 10/90/30, 40/60/30, 50/50/30, 60/40/30, and 90/10/30.

Briquettes making process. Prior to use, all materials were cut into pieces and dried naturally for about 5 days to remove physical moisture content. The ANS was then carbonized using an electrical furnace at the temperature of 250°C for 1-2 hours. All materials were saw-milled and sieved to obtain the required sizes (i.e. 100, 150, and 500µm), using the similar procedure in our previous report[43]. The particle size was classified as small (100 µm), medium (150 µm), and large sizes (500 µm). All materials were then mixed according to the predetermined variations. The binder of tapioca starch was made by the ratio of tapioca/water of 2/25. The tapioca starch was then mixed with the mixed material and stirred to form a dough. The dough was molded (round shape, 3.80 cm in diameter, and 0.70 cm in height) and pressed with a pressure of 8.74 N/cm^2. The briquettes were dried naturally to remove outer moisture. Then, they were dried at 150ºC in the electrical furnace until their mass is constant.

Briquette performance analysis. The prepared briquettes were tested by several characterizations: density, moisture content, water boiling test, burning rate, specific fuel consumption, water-resistance index, and durability index [44].

(1) Density includes compressed density (*CD*), relaxed density (*RD*), and relaxation ratio (*RR*). *CD, RD,* and *RR* were calculated using Eqs. (1), (2), and (3), respectively.

$$CD = W_c/V_c, \quad (1)$$

$$RD = W_r/V_r, \quad (2)$$

$$RR = CD/RD, \quad (3)$$

where *Wc* is the weight of the briquette immediately after molding, and *Vc* is the volume of the briquette after molding. *Wr* is the weight of briquettes after drying, and *Vr* is the volume of briquettes.

(2) Percentage moisture content (*PMC*) was determined by calculating the initial mass of briquettes immediately after molding (W_1), and the mass of briquettes after complete drying (W_2)[45]. *PMC* is calculated with Eq. (4).

$$PMC = [(W_1 - W_2)/W_2] \text{ X } 100\%. \quad (4)$$

(3) Water boiling test (*WBT*) is a test used to determine the efficiency of briquette combustion. It was carried out by burning the briquette sample, the heat from the combustion was used to boil 100 mL of water in a beaker. The increase in water temperature was recorded during the combustion process.

(4) Burning rate (*BR)* is the combustion rate which was calculated by the ratio of the mass lost when combustion with the total time used [46], calculated using Eq. (5).

$BR = Q/T$, (5)

where Q is the mass of briquette burnt out (g) and T is the total burning time (min).

(5) Specific fuel consumption (*SFC*) shows the ratio of the mass of the briquettes burned to the amount of water to boil [46] and it is determined using Eq. (6).

$SFC = Q/V$, (6)

where Q is the mass of burning briquettes (g) and V is the volume of boiling water (mL).

(6) Percentage of water resistance index (*PWRI*) test was conducted by immersing the briquettes in water with a temperature of 27ºC for 30 seconds[47]. *PWRI* is calculated using Eq. (7) and (8).

$PWA = [(Q_2\text{-}Q_1)/Q_1] \text{ X } 100$, (7)

$PWRI = 100\% - PWA$, (8)

where *PWA* is the percentage of water absorbed, Q_1 is the initial mass of briquettes (g), and Q_2 is the final mass of briquettes (g).

(7) Percentage of durability index (*DI*). To analyze *DI*, the mass of the briquettes was measured. The briquettes were put into a plastic bag, while the air in the plastic was removed. The briquettes were dropped from a height of 2 m onto a solid surface. The mass of the briquettes that were not crushed was then measured again [47]. The *DI* is determined by Eq. (9).

$DI = Q_2/Q_1 \text{X}100$, (9)

where Q_1 is the mass before being put together (g), and Q_2 is the mass after being dropped (g).

(8) Mechanical test. To analyze the mechanical characteristics of the briquettes, we carried out a compressive test and a puncture test [29,28]. The compressive test was performed using a screw stand test instrument (Mode I ALX-J, China) equipped with a measuring instrument (a Digital Force gauge (Model HP-500, Serial No. H5001909262). The puncture test was done using the Shore Durometer instrument (Shore A Hardness, In size, China). The compressive test was carried out by pressing the briquettes. The pressure given by the instrument to measure the hardness of the briquette, the measurement results are represented as a curve. The puncture test was done by inserting a needle into the surface of the briquette. The measured number was obtained from the depth of the needle puncture

3. Results and discussion

Effect of particle size

Density. Figure 1(a) shows the density in terms of *CD, RD,* and *RR* of the briquettes under varying particle sizes. The *CD* value varied from 1.10 to 1.38 g/cm^3. The highest *CD* value was obtained at the medium particle size of medium sizes. The lowest *CD* values were found in the large particles. The particle size affects the *CD* value, the larger particles resulted in a higher *CD* value [48]. However, anomalies were found in the sample with large particles. This can be due to the incomplete drying of the briquettes, the difference in the pressure exerted on the briquettes with large particles, or the effect of the binders used [41].

The *RD* value ranged from 0.60-0.90 g/cm^3. Briquettes with small particles showed the highest *RD* value, while briquettes with large particles showed the lowest *RD* value. Based on Fig. 1, the smaller particles allowed the obtainment of higher RD. The smaller particles made the larger binding surface area among the particle; Thus, the density was getting higher [49].

The *RR* of samples ranged from 1.3 to 1.7. The density changed from wet to dry, but briquettes were relatively stable. Variations in particle size had a different effect on the *RR*. The highest *RR* was obtained from briquettes with medium and large particles, while the lowest *RR* was obtained from small particles. This *RR* test showed that the most stable briquettes were the briquettes made with small particles. Small particles caused high briquette density [49].

Percentage moisture content (PMC). Figure 1(b) shows the results of *PMC* analysis on briquettes with different particle sizes. The *PMC* values ranged from 48 to 56%. Results showed that the relative moisture of the briquettes increased with the smaller particles. The highest *PMC* was obtained from briquettes with small particles, while the lowest *PMC* was obtained from large particles. Small particles allowed the briquette to have smaller pores. Small pores hold the transport of moisture and oxygen into the briquette [50].

Percentage of water resistance index (PWRI). PWRI is an analysis that shows the percentage of water content absorbed by the briquette with the effect of particle size (Fig. 1(b)). The highest *PWRI* was obtained for briquettes with large particles, while the lowest *PWRI* was obtained for the medium particles. The large particles make briquettes have many pores. The pores make the cavity on the briquettes and cause infiltration water to the briquette to become higher [51]. However, anomalies were found in samples with medium particle sizes which had a smaller PWRI value than small particles. It can be caused by differences in drying temperature and briquetting pressure when the medium particle size briquettes were made.

Percentage of durability index (DI). The sample showed good *DI* values ranging between 96.5 and 97.9% (Fig. 1(b)). The highest *DI* was obtained when using briquettes from small particles, while the lowest *DI* was obtained from large particles. The smaller particles allowed the obtainment of high density, indeed causing the briquettes to get stronger [52].

Burning rate (BR). Figure 1 (c) shows the effect of particle size on the *BR* of combustion. The *BR* value obtained ranged from 0.55 to 0.78 g/min. The largest *BR* was shown by the briquettes with large particles, and the smallest *BR* was indicated by the briquettes with medium particle size. The smaller particles caused lower porosity, so that mass transfer (i.e. water vapor, volatile matter, and oxygen infiltration) was inhibited. The inhibited mass transfer resulted in a higher *BR* [53]. Large particle shows that are not linear with the theory, this can occur due to the effect of differences in humidity, errors during briquette drying, or errors in the combustion treatment.

Specific fuel consumption (SFC). The results of *SFC* were presented, ranging from 0.066 to 0.1 g/mL (Fig. 1(c)). The lowest *SFC* value was obtained by the medium size, while the highest *SFC* was obtained in the sample with large particles. Briquettes made from large particles produced a large calorific value when they are burned. The high calorific value caused a high *SFC* value. The higher calorific value of the briquette combustion resulted in a better quality of briquettes [54].

Water boiling test (WBT). The water boiling test evaluates the thermal efficiency of briquettes [55]. Table 2 shows the results of the water boiling test (*WBT*) on variations in particle size. The data explains that the smaller particles of TD, ANS, and CN caused the water temperature to increase quickly. The best briquettes from the *WBT* test results are briquettes with small particles. Small particles in the briquettes have a low cavity, even almost non-porous. The less porous causes a higher calorific value so that the burning of the briquettes can increase the water temperature quickly.

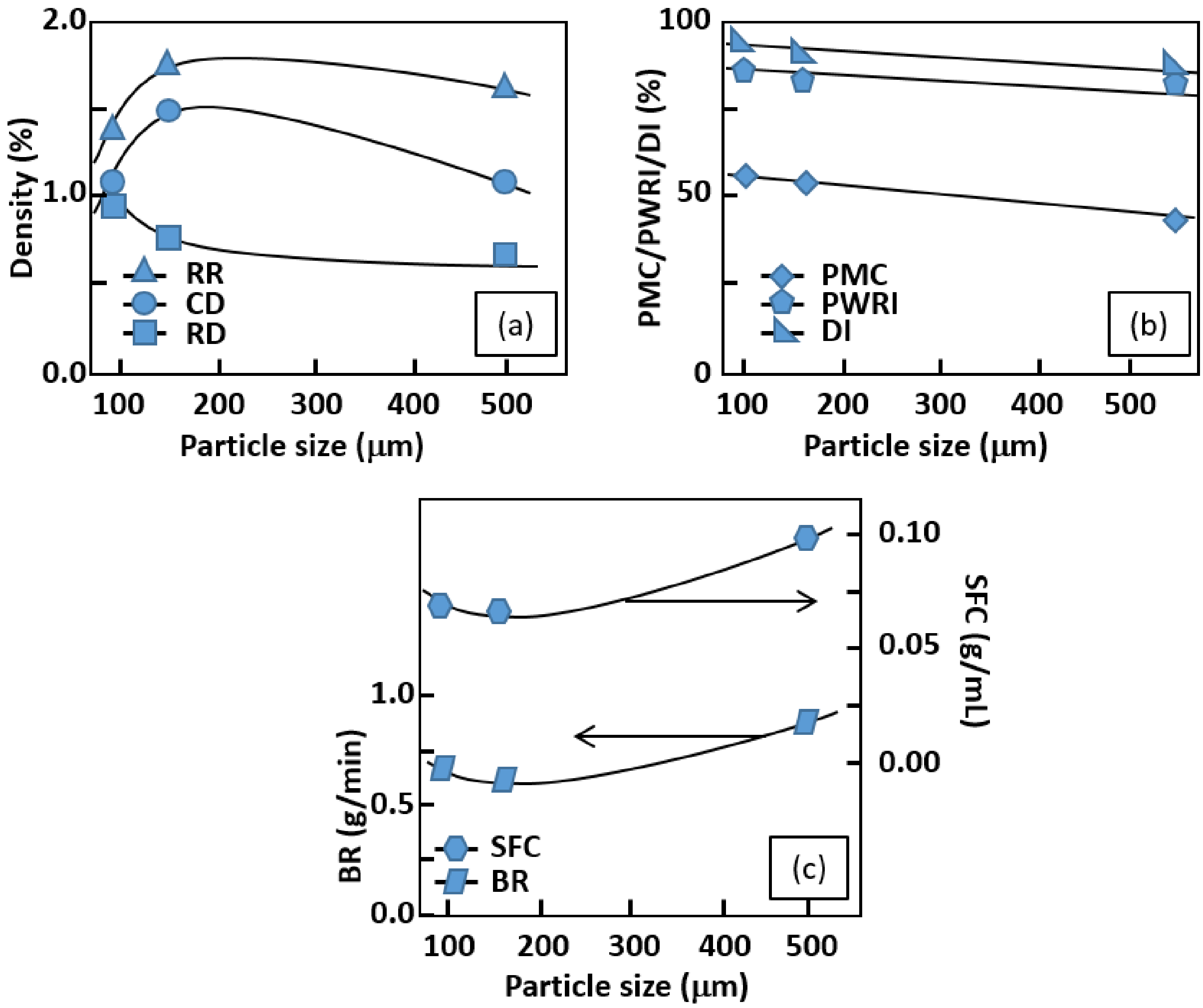

Fig. 1. Effect of particle size on briquettes' performance: (a) *CD, RD, RR,* (b) *PMC, PWRI, DI* (c) *BR* and *SFC*

Table 2. Water boiling test (*WBT*) as a function of particle size of

Particle size (μm)	Burning time (min)	Initial temperature (°C)	Final temperature (°C)
500	6.10		84
150	6.01	27	88
100	5.50		90

Variations of composition

Density. Figure 2 (a) shows the *CD, RD,* and *RR* of the briquettes with varying particle sizes. The density is an important parameter that can affect the quality of briquettes. In general, higher densities result in better briquette quality [56]. The highest *CD* was obtained at the raw material composition ratio of 50/50/30. The lowest *CD* was obtained at the ratio with the raw material composition of 90/10/30. The same ratio between TD and ANS resulted in high *CD* values. The more TD results in the smaller *CD* value. This can be caused by the characteristics of the TD material which cause many pores in the briquette, causing the briquette density to decrease. The density was affected by the size and homogeneity of the briquette constituents.

The *RD* value of briquettes ranged from 0.7 to 0.8 g/cm^3. The highest *RD* value was obtained in the material ratio of 40/60/30 and 50/50/30, while the lowest value was shown by briquettes with a ratio of 10/90/30, 60/40/30, and 90/10/30. From these results, it can be analyzed that the high carbon content of ANS causes a high *RD* value. However, briquettes with a ratio of 10/90/30 show anomalies. This anomaly could be caused by various possibilities such as the error of the researcher in making measurements, the inaccuracy of measuring instruments, errors in drying briquettes, and so on.

ANS carbon could create high RD values because of lower moisture content. The lower moisture content resulted in a greater RD value [48]. However, our results show an anomaly in the results of TD/ANS/CN were 10/90/30. This can be caused by errors in the production process (pressure, temperature, etc.) [57].

The *RR* value of samples with composition ratios of 10/90/30 and 60/40/30 was the highest. Meanwhile, briquettes with the ratios of 40/60/30, 50/50/30, and 90/10/30 show a low *RR* value. The results are almost inversely proportional to the *RD* value. The greater *RD* value resulted in the *RR* value. The anomaly was shown by briquettes with a ratio of 90/10/30, which still had a low *RR* value even though it had a low *RD* value. This anomaly might be caused by briquettes with a ratio of 90/10/30, which had not dried completely during the drying process. But in general, the *RR* value indicated that the change in briquette density from wet to dry, and is relatively stable. The mean *RR* values ranged from 1.7 to 1.8. The range of these values is quite good. Other reports showed the *RR* values ranging from 1.8 to 2.25 using coconut coir, and the other is from 1.65 to 1.80 using rice straw [58].

Percentage moisture content (PMC). The *PMC* values ranging from 50 to 56% are shown in Figure 3 (b). The highest *PMC* value was obtained from briquettes with compositions of 50/50/30 and 60/40/30 and the lowest *PMC* values were obtained from briquettes with a composition of 10/90/30. A high *PMC* value indicates the high humidity of the briquette. High humidity will make the briquettes produce a lot of smoke when they are burned [59]. The higher content of ANS resulted in a lower *PMC*. The carbonization process on the ANS reduces the moisture of ANS [60].

Percentage of water resistance index (PWRI). The results of *PWRI* varied between 82 and 91% are shown in Fig. 3(b). The *PWRI* indicates the resistance of the briquette to the water. The good have high *PWRI*. Thus, they are not easily destroyed when absorbing water [61]. The lowest *PWRI* value was obtained at the raw material composition ratio of 60/40/30. The highest *PWRI* value was obtained at the raw material composition ratio of 90/10/30. The TD material caused the briquettes to have a high *PWRI*. The briquettes from TD have a low moisture content [3]. Low moisture content increases the resistance of briquettes to water [62]; therefore, the briquettes with a high TD concentration are more resistant to water.

Burning rate (BR). The results of *BR* shown in Fig. 3(c) ranged from 0.55 to 0.84 g/min. The highest value was indicated by the material ratio of 10/90/30 and the lowest value was indicated by the material ratio of 50/50/30. The *BR* value is affected by the density of the briquette. The denser briquette resulted in the longer briquettes running out when it is burned. This is due to the higher the briquette's compacting pressure and processing temperature caused to higher density and energy content per unit volume of briquettes [63].

Percentage of durability index (DI). Figure 3 (b) shows the *DI* value. The results of the study showed a good *DI* value, where the average was between 94.9 and 96.2%. The highest *DI* value was obtained from briquettes with TD/ANS/CN at the ratio of 40/60/30, while the lowest *DI* value was obtained at a ratio of 60/40/30. The briquettes with a higher ANS ratio showed a higher *DI* value than other briquettes because the ANS particle had a smaller surface area. This can be seen from the smaller ANS particles that make the higher density. The high density makes the briquettes not easily crushed. The high density of briquettes improves the handling properties and compressive strength of the briquettes [64].

Specific fuel consumption (SFC). Based on Figure 2 (d), the *SFC* value varied between 0.066 and 0.097 g/mL. Briquettes with a larger ANS composition showed a higher *SFC*. The lowest *SFC* value was obtained at the variation of the raw material composition ratio of

50/50/30. The best briquettes were found at a TD/ANS/CN ratio of 40/60/30. The *SFC* value shows the quantity of fuel needed to boil water. Therefore, the greater the *SFC* value resulted in the better quality of the briquettes.

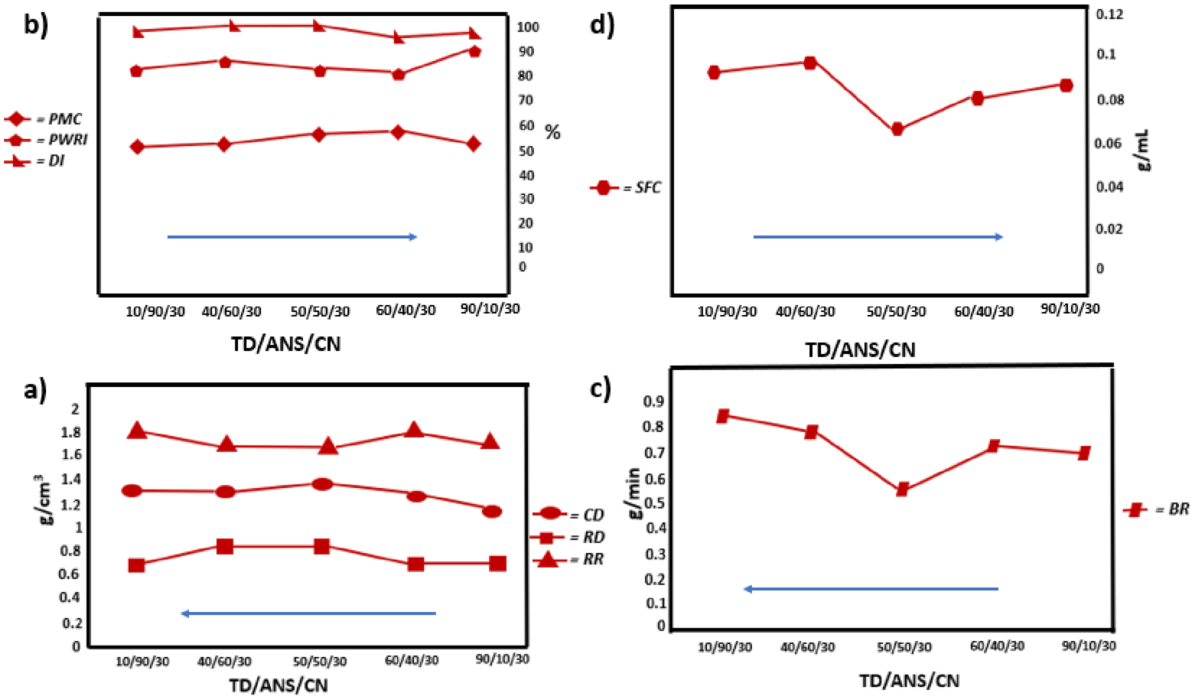

Fig. 2. Analysis composition variations on several parameters: (a) *CD, RD, RR*, (b) *PMC, PWRI, DI (c) BR*, and (d) *SFC*

Water boiling test (WBT). Table 3 shows the results of the water boiling test (*WBT*) on variations in the raw material composition of TD/ANS/CN. The water boiling test evaluates the efficiency of briquettes to increase the temperature [55]. The data obtained explains that the mix of TD/ANS/CN ingredients with a ratio of 50/50/30 maximizes the quality of the briquettes. The high ANS carbon content reduces the humidity of the briquettes so that moisture does not hinder the combustion process.

Table 3. Water boiling test (*WBT*) as a function of TD/ANS/CN ratio

TD/ANS/CN ratio	Burning time (min)	Initial temperature (°C)	Final temperature (°C)
10/90/30	5.57	27	86
40/60/30	6.29		85
50/50/30	6.01		88
60/40/30	5.52		84
90/10/30	6.15		85

Mechanical test. Figure 3 shows the results of the compressive test. The level of briquette hardness was expressed by the height of the curve peak (maximum force). The briquettes with varying particle sizes show the peak from low to high respectively indicated by the large, medium, and small size particles. The smaller the particle size made the briquettes harder. Briquettes with a small particle size have a high density because the bonds between the particles are tighter [65]. The addition of a tapioca starch binder also makes each particle of the material bind more strongly [66].

The curve peaks of the briquettes with variations in material composition (medium particle size) were scattered between the peaks of the large and small particles. However, the peak of the briquette curve with a composition of 10/90/30 looks higher than the peak of the briquette curve with medium size. This result is due to the effect of the high ANS content. ANS carbon could increase the hardness of the briquettes, making the briquettes stronger from collisions.

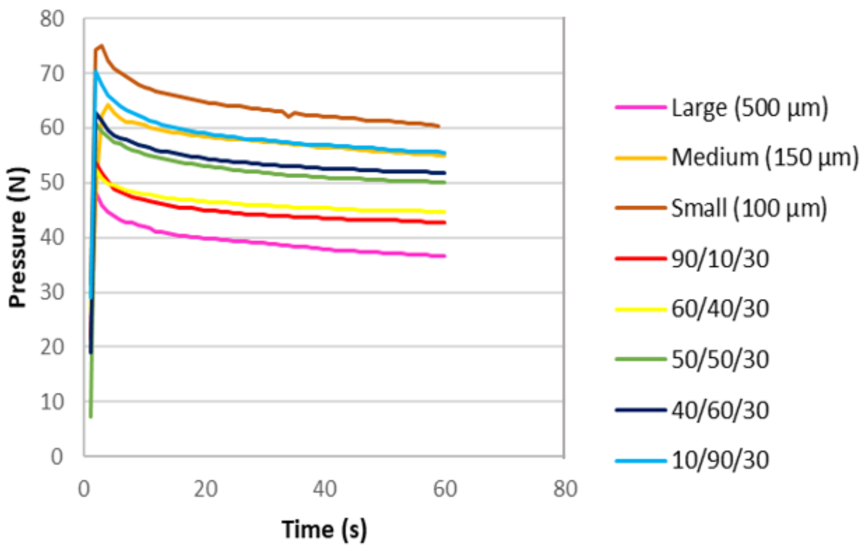

Fig. 3. Compressive test of all sample's briquettes

Table 4. Puncture test analysis results as a function of particle size and TD/ANS/CN ratio

No	Particle size (µm)			TD/ANS/CN ratio				
	500	150	100	90/10/30	60/40/30	50/50/30	40/60/30	10/90/30
1	95	65	30	70	73	60	57	45
2	92	73	34	78	69	67	53	45
3	95	64	45	74	74	66	61	40
4	92	70	43	72	73	72	56	42
5	92	66	35	78	74	69	61	45
average	93.20	67.60	37.40	74.40	72.60	66.80	57.60	43.40

Table 4 shows the results of the puncture test. The hard and compact briquettes make the needle more difficult to puncture so that the average puncture test result will be small. Conversely, briquettes that are not hard and porous make it easier for the needle to puncture the briquette so that the average puncture test result will be large. In line with the results of the compressive test, briquettes with large particles showed a large puncture test result, while the smaller the particle size indicated a smaller puncture test result. The results of the briquette puncture test with variations in the composition were spread between 37.40 and 93.20. This result was greater than the average result of briquettes with small particles' puncture test. It is smaller than the average result of briquettes with large particles' puncture test. This can occur because the briquettes with various material compositions were made with medium particle size. The level of hardness of briquettes was influenced by particle size, characteristics of the material, and compressive strength.

4. Conclusion

The effect of particle size and biomass ratio on the quality of briquettes obtained from TD, ANS, and CN has been investigated. The study has several novelties, which relate to the improvement of briquettes' quality: (i) the evaluation of particle size of raw materials; (ii) effects of the composition of raw materials; (iii) combination of carbon and dried biomass; and (iv) the use of raw materials that are almost unused and typically disposed directly to the environment. The best briquettes are briquettes with small particles (100 µm) and TD/ANS/CN biomass ratios of 40/60/30 and 10/90/30. The briquettes will be better if the smaller the particle size and the more ANS ratio is used. The high ANS ratio makes the compressive strength high because the ANS particle has a smaller surface area. ANS which is smaller makes the resulting particle denser when compared to TD. This research is important because it utilizes biomass as an alternative fuel to reduce environmental pollution. The good quality briquettes were dense, having low moisture, good strength, and waterproof, as well as high heating value and low burning times.

References

1. Nizamuddin S, Baloch HA, Griffin GJ, Mubarak NM, Bhutto AW, Abro R, Mazari SA, Ali BS. An overview of effect of process parameters on hydrothermal carbonization of biomass. *Renewable and Sustainable Energy Reviews*. 2017;73: 1289-1299.
2. Dani S, Wibawa A. Challenges and policy for biomass energy in Indonesia. *International Journal of Business*, *Economics, and Law*. 2018;15(5): 41-47.
3. Indrawijaya B, Fathurrohman A, Nisa H. Pembuatan dan karakterisasi briket bahan bakar dari ampas tahu sebagai energi alternatif synthesis and characterization fuel briquettes from tofu dregs as alternative energy. *Jurnal Ilmiah Teknik Kimia*. 2018;2(1): 38-44.
4. Carnaje NP, Talagon RB, Peralta JP, Shah K, Paz-Ferreiro J. Development and characterisation of charcoal briquettes from water hyacinth (Eichhornia crassipes)-molasses blend. *PloS one*. 2018;13(11): e0207135.
5. Deepak K, Manujesh B, Vivek, Yashas B. Development and study of fuel briquettes from areca leaves: A potential renewable energy source. *AIP Conference Proceedings*. 2019;2080(1): 030004.
6. Suryaningsih S, Resitasari R, Nurhilal O Analysis of biomass briquettes based on carbonized rice husk and jatropha seed waste by using newspaper waste pulp as an adhesive material. *Journal of Physics: Conference Series*. 2019;1280(2): 022072
7. Aliyu M, Mohammed IS, Usman M, Dauda SM, Igbetua JI. Production of composite briquettes (orange peels and corn cobs) and determination of its fuel properties. *Agricultural Engineering International: CIGR Journal*. 2020;22(2): 133-144.
8. Nandiyanto ABD, Bustomi ATA, Sugiarti Y, Santiuly GC. The effect of electronic module utilization for biomass briquettes experiment using cocoa shells and sea mango to vocational school students. *Journal of Engineering Education Transformations*. 2020;34: 115-123.
9. Brunerová A, Roubík H, Brožek M, Van Dung D, Phung LD, Hasanudin U, Iryani DA, Herak D. Briquetting of sugarcane bagasse as a proper waste management technology in Vietnam. *Waste Management and Research*. 2020;38(11): 1239-1250.
10. Nandiyanto ABD, Rachmat LA, Rahayu DL, Azizah NN, Al Husaeni DF. Development of job sheet application in making biobriquette based on coconut (cocos nucifera) coir with variation of particle size and banana (musa paradisica) peels for vocational students. *Journal of Engineering Education Transformations*. 2020;34: 132-138.
11. Nandiyanto ABD, Rohman E, Handayani MN, Putri SR. E-Module in producing briquettes from melinjo (gnetum gnemon) shell with various particle sizes and binder concentrations for vocational school students. *Journal of Engineering Education Transformations*. 2020;34: 57-64.
12. Bot BV, Sosso OT, Tamba JG, Lekane E, Bikai J, Ndame MK. Preparation and characterization of biomass briquettes made from banana peels, sugarcane bagasse, coconut

shells and rattan waste. *Biomass Conversion and Biorefinery*. 2021. Available from: https://doi.org/10.1007/s13399-021-01762-w.
13. Anggraeni S, Putri SR, Nandiyanto ABD, Bilad MR. Effect of particle size and tapioca starch content on performance of the rice husk and red bean skin briquettes. *Journal of Engineering Science and Technology*. 2021;16(2): 1733-1745.
14. Wirabuana AD, Alwi RS. Influence of starch binders composition on properties of biomomass briquettes from durian peel (durio kutejensis becc). *AIP Conference Proceedings*. 2021;2349(1): 020020.
15. Anggraeni S, Hofifah S, Nandiyanto ABD, Bilad MR. Effects of particle size and composition of cassava peels and rice husk on the briquette performance. *Journal of Engineering Science and Technology*. 2021;16(1): 527-542.
16. Akolgo GA, Awafo EA, Essandoh EO, Owusu PA, Uba F, Adu-Poku KA. Assessment of the potential of charred briquettes of sawdust, rice and coconut husks: Using water boiling and user acceptability tests. *Scientific African*. 2021;12: e00789.
17. Anggraeni S, Nandiyanto ABD, Putri SR, Anshar AN, Maulana A, Nurazizah S, Nurjihan Z, Al-Obaidi ASM. Mechanical Properties of briquette by mixing rice and micrometer-sized carbon particles from potato and yam skins. *Journal of Engineering Research*. 2021;9(ASSEEE special issue): 1-15.
18. Velusamy S, Subbaiyan A, Kandasamy S, Shanmugamoorthi M, Thirumoorthy P. Combustion characteristics of biomass fuel briquettes from onion peels and tamarind shells. *Archives of Environmental & Occupational Health*. 2022;77(3): 251-262.
19. Anggraeni S, Girsang GCS, Nandiyanto ABD, Bilad MR. Effects of particle size and composition of sawdust/carbon from rice husk on the briquette performance. *J. Eng. Sci. Technol*. 2021;16(3): 2298-2311.
20. Nandiyanto ABD, Tahira AC, Anwar B, Maryanti R. The impact of teaching the effects of dextrin binder composition on bamboo fiber and dried clove leaves briquettes to high school students. *Journal of Engineering Education Transformations*. 2020;34: 65-74.
21. Nandiyanto ABD, Widiaputri SI, Maharani S, Ragadhita R. Job sheet learning media on briquette production from coffee grounds and soybean peel with various compositions and particle sizes for vocational high school students. *Journal of Engineering Education Transformations*. 2020;34: 139-146.
22. Nandiyanto ABD, Simbara AT, Mudzakir A, Maryanti R. Improving the learning process in producing bio-charcoal briquettes from durian peels/banana midrib with various particle sizes and composition to high school students. *Journal of Engineering Education Transformations*. 2020;34: 32-42.
23. Nandiyanto ABD, Tiyana R, Azizah DN, Hofifah SN. Demonstrating the biobriquettes production using variations in particle size and binder concentration using audio-visual to vocational students. *Journal of Engineering Education Transformations*. 2020;34: 87-94.
24. Triawan F, Nandiyanto ABD, Abdullah AG, Aziz M. Plasma nitriding time on the hardness and crystal structure/phase of SUS403 and SCS6 martensitic stainless steels: an analytical study. *Journal of Engineering Science and Technology*. 2018;13(8): 2369-2378.
25. Nandiyanto ABD, Triawan F, Firly R, Abdullah AG, Aono Y, Inaba K, Kishimoto K. Identification of micro-mechanical characteristics of monoclinic tungsten trioxide microparticles by nanoindentation technique. *Materials Physics and Mechanics*. 2019;42(3): 323-329.
26. Nandiyanto ABD. Crystallite Size on Micromechanical Characteristics of WO3 Microparticles. *Journal of Engineering Research*. 2021;9(3A): 268-277.
27. Nandiyanto ABD, Hofifah SN, Girsang GCS, Putri SR, Budiman BA, Triawan F, Al-Obaidi ASM. The effects of rice husk particles size as a reinforcement component on resin-based brake pad performance: From literature review on the use of agricultural waste as a

reinforcement material, chemical polymerization reaction of epoxy resin, to experiments. *Automotive Experiences*. 2021;4(2): 68-82.
28. Triawan F, Nandiyanto ABD, Suryani IO, Fiandini M, Budiman BA. The influence of turmeric microparticles amount on the mechanical and biodegradation properties of cornstarch-based bioplastic material: From bioplastic literature review to experiments. *Materials Physics and Mechanics*. 2020;46(1): 99-114.
29. Nandiyanto ABD, Fiandini M, Ragadhita R, Sukmafitri A, Salam H, Triawan F. Mechanical and biodegradation properties of cornstarch-based bioplastic material. *Materials Physics and Mechanics*. 2020;44(3): 380-391.
30. Anggraeni S, Nandiyanto ABD, Nurjami A, Hofifah SN, Putri SR, Girsang GC, Fiandini M. Palm oil and cinnamon (anti-microbial agent) on the physicochemical, mechanical, and biodegradation properties of micrometer-sized cornstarch-based bioplastic. *Moroccan Journal of Chemistry*. 2021;9(3): 2446-2453.
31. Anggraeni S, Hotimah AP, Girsang GCS, Ragadhita R, Hofifah SN, Nandiyanto ABD. Teaching the Effect of Flour on Mechanical Properties of Shrimp Shell Crackers ‘Kerupuk’to High School Students. *Journal of Engineering Education Transformations*. 2020;34: 75-80.
32. Ragadhita R, Nandiyanto ABD. How to calculate adsorption isotherms of particles using two-parameter monolayer adsorption models and equations. *Indonesian Journal of Science and Technology*. 2021;6(1): 205-234.
33. Yolanda YD, Nandiyanto ABD. How to read and calculate diameter size from electron microscopy images. *ASEAN Journal of Science and Engineering Education*. 2022;2(1): 11-36.
34. Nandiyanto ABD, Oktiani R, Ragadhita R. How to read and interpret FTIR spectroscope of organic material. *Indonesian Journal of Science and Technology*. 2019;4(1): 97-118.
35. Fatimah S, Ragadhita R, Al Husaeni DF, Nandiyanto ABD. How to calculate crystallite size from x-ray diffraction (XRD) using Scherrer method. *ASEAN Journal of Science and Engineering*. 2022;2(1): 65-76.
36. Al Husaeni DF, Nandiyanto ABD. Bibliometric using Vosviewer with Publish or Perish (using google scholar data): From step-by-step processing for users to the practical examples in the analysis of digital learning articles in pre and post Covid-19 pandemic. *ASEAN Journal of Science and Engineering*. 2022;2(1): 19-46.
37. Ismanto SD, Murtius WS. Characteristics of chicken sausage treated with using tofu dregs waste. *International Journal on Advanced Science, Engineering and Information Technology*. 2013;3(4): 318-321.
38. Sari LM, Hakim RF, Mubarak Z, Andriyanto A. Analysis of phenolic compounds and immunomodulatory activity of areca nut extract from Aceh, Indonesia, against Staphylococcus aureus infection in Sprague-Dawley rats. *Veterinary World*. 2020;13(1): 134.
39. Kusumaningrum HP, Zainuri M, Endrawati H, Purbajanti ED. Characterization of citronella grass essential oil of Cymbopogon winterianus from Batang region, Indonesia. *Journal of Physics: Conference Series*. 2020;1524(1): 012057.
40. Murni S, Pujiastuti SS, Octoria D. Improving the production quality of atsiri oil industry through the introduction of equipment and diversification of raw materials. *Review of Integrative Business and Economics Research*. 2017;6: 32.
41. Helwani Z, Ramli M, Rusyana A, Marlina M, Fatra W, Idroes GM, Suhendra R, Ashwie V, Mahlia TMI, Idroes R. Alternative briquette material made from palm stem biomass mediated by glycerol crude of biodiesel byproducts as a natural adhesive. *Processes*. 2020;8(7): 777.
42. Seo MW, Jeong HM, Lee WJ, Yoon SJ, Ra HW, Kim YK, Lee D, Han SW, Kim SD, Lee JG. Carbonization characteristics of biomass/coking coal blends for the application of bio-coke. *Chemical Engineering Journal*. 2020;394: 124943.

43. Nandiyanto ABD, Andika R, Aziz M, Riza LS. Working volume and milling time on the product size/morphology, product yield, and electricity consumption in the ball-milling process of organic material. *Indonesian Journal of Science and Technology*. 2018;3(2): 82-94.
44. Sotannde OA, Oluyege AO, Abah GB. Physical and combustion properties of charcoal briquettes from neem wood residues. *International Agrophysics*. 2010;24(2): 189-194.
45. Singh RN. Equilibrium moisture content of biomass briquettes. *Biomass and Bioenergy*. 2004;26(3): 251-253.
46. Onuegbu TU, Ekpunobi UE, Ogbu IM, Ekeoma MO, Obumselu FO. Comparative studies of ignition time and water boiling test of coal and biomass briquettes blend. *IJRRAS*. 2011;7(2): 153-159.
47. Rajaseenivasan T, Srinivasan V, Qadir GSM, Srithar K. An investigation on the performance of sawdust briquette blending with neem powder. *Alexandria Engineering Journal*. 2016;55(3): 2833-2838.
48. Bello RS, Onilude MA. Physico-mechanical characteristics of high density briquettes produced from composite sawdust. *Journal of Applied Sciences and Environmental Management*. 2020;24(5): 779-787.
49. Mitchual SJ, Frimpong-Mensah K, Darkwa NA. Effect of species, particle size and compacting pressure on relaxed density and compressive strength of fuel briquettes. *International Journal of Energy and Environmental Engineering*. 2013;4(1): 1-6.
50. Zhang G, Sun Y, Xu Y. Review of briquette binders and briquetting mechanism. *Renewable and Sustainable Energy Reviews*. 2018;82: 477-487.
51. Fiandini M, Ragadhita R, Nandiyanto ABD, Nugraha WC. Adsorption characteristics of submicron porous carbon particles prepared from rice husk. *Journal of Engineering, Science and Technology*. 2020;15: 022-031.
52. Zhang J, Guo Y. Physical properties of solid fuel briquettes made from Caragana korshinskii Kom. *Powder Technology*. 2014;256: 293-299.
53. Davies RM, Abolude DS. Ignition and burning rate of water hyacinth briquettes. *Journal of Scientific Research and Reports*. 2013;2(1): 111-120.
54. Kongprasert N, Wangphanich P, Jutilarptavorn A. Charcoal briquettes from madan wood waste as an alternative energy in Thailand. *Procedia Manufacturing*. 2019;30: 128-135.
55. Sawadogo M, Tanoh ST, Sidibé S, Kpai N, Tankoano I. Cleaner production in Burkina Faso: Case study of fuel briquettes made from cashew industry waste. *Journal of Cleaner Production*. 2018;195: 1047-1056.
56. Rahmawati S, Sakung J, Fudholi A, Sushmita L. The utilization of corncob for the manufacture of charcoal briquette as an alternative fuel. *Journal of Physics: Conference Series*. 2020;1563(1): 012022.
57. Nakashima GT, Martins MP, Hansted ALS, Yamamoto H, Yamaji FM. Sugarcane trash for energy purposes: Storage time and particle size can improve the quality of biomass for fuel? *Industrial Crops and Products*. 2017;108: 641-648.
58. Oladeji JT, Enweremadu CC. The effects of some processing parameters on physical and densification characteristics of corncob briquettes. *International Journal of Energy Engineering*. 2012;2(1): 22-27.
59. Aransiola EF, Oyewusi TF, Osunbitan JA, Ogunjimi LAO. Effect of binder type, binder concentration and compacting pressure on some physical properties of carbonized corncob briquette. *Energy Reports*. 2019;5: 909-918.
60. Nazari MM, Idroas MY, Ayuni FA. Carbonization effect on EFB briquettes prepared with different type of binders. *IOP Conference Series: Earth and Environmental Science*. 2020;476(1): 012072.
61. Zanjani NG, Moghaddam AZ, Dorosti S. Physical and chemical properties of coal briquettes from biomass-bituminous blends. *Petroleum and Coal*. 2014;56(2): 188-195.

62. Yaman S, SahanŞahan M, Haykiri-Acma H, Şeşen K, Küçükbayrak S. Fuel briquettes from biomass–lignite blends. *Fuel Processing Technology*. 2001;72(1): 1-8.
63. Olugbade T, Ojo O, Mohammed T. Influence of binders on combustion properties of biomass briquettes: a recent review. *BioEnergy Research*. 2019;12(2): 241-259.
64. Hamid MF, Idroas MY, Ishak MZ, Zainal Alauddin ZA, Miskam MA, Abdullah MK. An experimental study of briquetting process of torrefied rubber seed kernel and palm oil shell. *BioMed Research International*. 2016;2016(1): 1-11.
65. Igbo KP. Physico-mechanical characteristics of rice husk briquettes using different binders. *Agricultural Engineering International: CIGR Journal*. 2016;18(1): 70-81.
66. Akogun OA, Waheed MA, Ismaila SO, Dairo OU. Co-briquetting characteristics of cassava peel with sawdust at different torrefaction pretreatment conditions. *Energy Sources, Part A: Recovery, Utilization, and Environmental Effects*. 2020;10: 1-19.

THE AUTHORS

A.B.D. Nandiyanto
e-mail: nandiyanto@upi.edu
ORCID: 0000-0002-9753-1267

S.N. Hofifah
e-mail: sitinurhofifah@upi.edu
ORCID: -

S. Anggraeni
e-mail: anggraeni_said@upi.edu
ORCID: -

N.Z. Latifah
e-mail: nurzahralatifah@upi.edu
ORCID: -

J.E. Sitanggang
e-mail: juliaelisabeth@upi.edu
ORCID: -

O. Sopian
e-mail: opisopian@upi.edu
ORCID: -

Z. Saputra
e-mail: ziyansaputra@upi.edu
ORCID: -