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"Evaluation of Bio Briquettes made from *Musa acuminata Colla*, *Musa acuminata* and *Musa balbisiana* Silk, and *Citrus reticulata* and *Citrus sinensis* Peels"

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ABSTRACT: Accumulation of food waste and the burning of coal emit harmful chemicals which contribute to environmental problems such as climate change and global warming. These also risk the health of people, which causes deaths. Briquettes help improve and preserve the environment by lessening food waste and coal emissions. This study aims to determine the best treatment for briquettes to help disadvantaged communities and alleviate the adverse effects on the environment and health. A combination of banana *(Musa acuminata Colla (AA Group) 'Lakatan' and Musa acuminata × M. balbisiana (AAB Group) 'Silk'*, and orange *(Citrus × reticulata and Citrus × sinensis)* peels were used as bases for the briquettes. Sawdust also served as a controlled treatment, and two different binder treatments were also used, namely paper pulp and cassava starch. The briquettes' quality was tested based on their density, burning rate, ignition time, and efficiency (Water Boiling Test). One-way Multivariate Analysis of Variance (One-way MANOVA), Shapiro-Wilk Normality Test and Levene's Homogeneity of Variances Test, One-way ANOVA, Post-Hoc Test, specifically Tukey's LSD were then used to analyze the gathered results. Results revealed that the best briquettes are orange & cassava (density), banana & paper (burning rate), sawdust & cassava (ignition), and sawdust & cassava (efficiency). The findings indicate that the best briquettes were sawdust & cassava (most efficient in Water Boiling Test and fastest to ignite) and banana & paper (lowest burning rate) briquettes. Additionally, the findings suggest different production practices.

KEYWORDS: fruit peels; binders; density; burning rate; efficiency; ignition time

INTRODUCTION

Food waste and coal contribute to the degradation of the environment and health. Food waste is accountable for producing 6% of greenhouse gas emissions (Ritchie & Roser, 2020). While consumers and supply chains contribute to ¼ of the emissions (Poore & Nemecek, 2018). Coal is a primary fuel source (Comedis et al., 2017). It comprises 10-30% inorganic components such as clay, quartz silt, and sand. When burned, sand has several environmental and health risks (Dai et al., 2016; Saikia et al., 2009; Singh et al., 2015). Bio-briquettes are a solution to all environmental problems created by food waste and coal.

Briquetting is one alternate process for converting biomass and municipal trash into useful products since the briquettes produced may be used as domestic and industrial fuel (Thulu et al., 2016). Converting wastes such as papers, fruit peelings, and sawdust using a simple process like the hand-press pasta maker has tremendous potential for home fuel and, eventually, as a substitute for charcoal. Briquettes are apt sources of fuel because they have a clean-burning nature. It can be stored for a long time without degrading (Thulu et al., 2016). Biomass briquettes reduce greenhouse gases and global temperature (Gangadhar et al., 2016) and prevent carbon emissions, decreasing health risks (Safana et al., 2018). Lastly, briquettes have two main components: the base and the binder.

Binders make the briquette durable because it acts as an adhesive that binds the fruit peels together (Young, 2015). When cassava starch is converted into a binder, it undergoes gelatinization, where proteins form solid bridge bonds that contribute to the briquette's overall quality (Kpalo et al., 2020). In a study by Aliyu et al. (2020) and Oladeji (2010), the cassava starch was mixed with water to form a gel consistency. Paper contains lignin that turns into a plasticized state when submerged in water for 3 to 5 days (Shyamalee et al., 2015). Tamilvanan (2013) submerged the paper in water for two days to form a paper pulp binder.

The base of the briquettes is the fruit peels, specifically, the banana and orange peels. These peels are renewable energy sources. They benefit the economic and environmental sectors that serve as suitable replacements for fossil fuels and a solution to food waste problems. Banana peels contain more energy than paper (Thulu et al., 2016). Orange peels have high carbon contents, making them a substitute for wood-based briquettes (Zanella et al., 2016). Both banana and orange peels possess fibers that allow the briquette to retain heat which increases the briquette's thermal value, making combustion more effective (ABC Machinery, 2021).

The following tests will be conducted to evaluate the briquettes' properties, such as density, burning rate, efficiency, and ignition time.

The density of the briquette characterizes the amount of energy a briquette can release. For instance, a briquette with a high density will release a significant amount of energy (Davies & Davies, 2013). Moreover, density and pressure are directly proportional (Yerima & Grema, 2018). Sunardi et al. (2019) also stated that density is directly proportional to burning time because it reduces moisture and ash contents. In a study by Aliyu et al. (2020), they used a combination of orange peels and corn cobs to produce and determine some solid fuel properties. The density was determined after the briquettes were ejected from the mold. A digital weighing scale was used to determine the mass, and a ruler was used to measure the briquette's r (radius) and h (height). The radius and height were substituted to the volume formula:

$$v = \pi r^2 h$$

Where:

v = volume (briquettes are cylindrical in shape,)

r = radius (m or cm)

h = height (m or cm)

After getting the volume and mass, the values were substituted to the density formula.

$$\rho = \frac{m}{v}$$

Where:

ϱ = density $(kg/m^3 \ or \ g/cm^3)$

m = mass of the briquette *(kg or g)*

v = volume of the briquettes $(m^3 \ or \ cm^3)$.

The burning rate test is used to determine the amount of fuel lost when the briquette is combusted (Mohammed & Olugbade, 2015). According to Chaengba et al. (2011), the ratio of the briquette's mass to the maximum amount of time it stays ignited is the fuel's burning rate in terms of grams per minute. It helps determine the amount of fuel needed for a specific time. During the burning phase, a stopwatch was used to monitor the briquette every 10 seconds until it burned and the final weight was obtained. The weight loss was then computed using the formula:

$$Burning\ Rate = \frac{Q1 - Q2}{T}$$

Where:

Br = burning rate *(g/min)*

Q1 = initial weight of fuel before cooking *(g)*

Q2 = final weight of fuel after cooking *(g)*

T =total burning time *(min)*.

In this study, the dry process will be used since Tamilvanan (2013) found that a biomass briquette created through a wet process (20 minutes) has a shorter time than a dry process (10 minutes). The wet process involves the materials being crushed with the binder. Whereas the dry process involves the crushed materials, the binder is added.

Efficiency compares the cooking performance of the briquettes by boiling the same amount of water under the same conditions (Ikelle & Ivoms, 2014). The method for testing the briquettes' efficiency is called the Water Boiling Test (WBT). The WBT conducts a simple simulation of the cooking process where the briquettes are used as fuel to heat the pot of water until the boiling point is reached (Sengar et al., 2012). A study by Thulu et al. (2016) had two treatments: banana peels & sawdust and waste paper & sawdust. These treatments were compared based on the combustion characteristics. Their study used the Water Boiling Test (WBT), and the results showed that banana peel & sawdust had an average of 12.6 minutes. In contrast, waste paper & sawdust briquettes took approximately 16.6 minutes

(Thulu et al., 2016). A similar approach was followed for this study. In this study, briquette groups will boil pots with the same amount of water, 250 ml, and the same target temperature, which is 90ºC.

Ignition time is the duration it takes to light the briquettes until it catches fire and combusts (Kabok et al., 2018). A stopwatch was used to monitor the amount of time it took for the briquettes to ignite. Ignition time is directly affected by the moisture content of the biomass and binders (Jolly et al., 2010). Gbabo et al. (2018) stated that different binder ratios and raw material properties affect the briquettes' characteristics. This statement is supported by a study by Ukpaka et al. (2019), where the increase in binder content increases ignition time.

The research aimed to turn waste into energy by producing briquettes from agricultural and food residues. The study considered time to create, efficiency, and affordability of the briquette to help energy deficit countries and low-income individuals. Therefore, providing renewable energy lessens the harmful impacts on the environment and health. The researchers used a manual pasta press to create the briquettes (Video Eppo, 2017). A combination of two different peels, specifically *Musa acuminata Colla 'Lakatan' and Musa acuminata × M. balbisiana 'Silk'* peels for the banana peels. For the orange peels, the researchers utilized a combination of *Citrus × reticulata and Citrus × sinensis.*

Several studies have used advanced technologies such as the hydraulic jack, piston press, and screw press to exert high pressure on the briquette (Aliyu et al., 2020; Sunardi et al., 2019; Thulu et al., 2016). The researchers used a manual pasta press to create the briquettes (Video Eppo, 2017). Other studies (Ikelle & Ivoms, 2014; Sharma et al.,2015; Sunardi et al., 2019; Thulu et al., 2016) utilized one type of peel. This study will use a combination of two different types of peels, specifically *Musa acuminata Colla 'Lakatan'* and *Musa acuminata × M. balbisiana 'Silk'* peels for the banana peels. For the orange peels, the researchers utilized a combination of *Citrus × reticulata* and *Citrus × sinensis*. The dependent variables include density, burning rate, ignition time, and efficiency because of the lack of professional help and equipment for the other tests. Due to COVID-19, the researchers conducted the experiments in their respective households, utilized a pasta manual press to make the briquettes, and followed safety precautions during briquette production.

The main objective of this study was to identify the optimum combination of base (banana peels/orange peels/sawdust) and binder (paper pulp/cassava starch) to produce the most efficient briquette. This has been done by experimenting with the density, burning rate, ignition time, and efficiency of the four treatments: treatment A (banana peels & paper pulp), treatment B (banana peels & cassava starch), treatment C (orange peels & paper pulp), treatment D (orange peels & cassava starch).

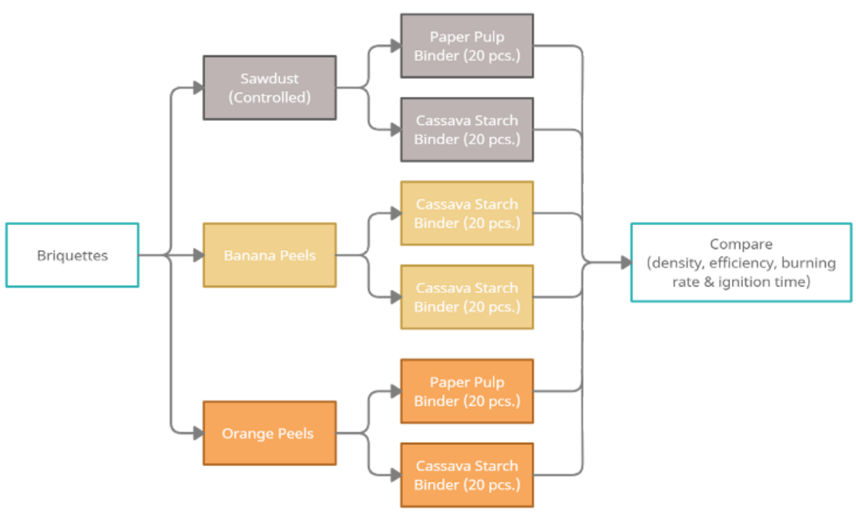
METHODOLOGY

Research Design

An experimental research design (Figure 1) was used to differentiate the effects of the peels and binders on the briquettes' quality since it is intended to see how the treatments affect the dependent variables (Harland, 2010). Furthermore, a stratified random sampling technique was used since the briquettes were divided into six homogenous groups. Hence, five briquettes per stratum were randomly assigned to a dependent variable for testing its quality.

Figure 1

Experimental design



Preparation of Peels and Binder

Drying and crushing fruit peels were inspired by a method previously described by Charbel et al. (2015). As shown in Figure 2, banana and orange peels were sun-dried for one week to reduce their moisture content. Then, the dried peels were crushed into small pieces and stored in a bag or container.

For the paper pulp binder (Figure 2), papers were shredded into pieces and submerged in water for 4 hours (Lockard, 2011). Then, it was blended until it formed a paper pulp mixture (Kpalo et al., 2020).

Figure 2

Paper pulp binder preparation

For the cassava starch binder (Figure 3), a mixture of 3.5 tablespoons of cassava starch and 6 cups of water was boiled at 800°C until it formed a gel-like consistency (Lockard, 2011). Then, it was left to cool down until room temperature.

Figure 3

Cassava starch binder preparation

Briquette Production

A ratio of 7 cups : 3 cups (binder: base) was used in combining the bases and binders (Withatanang et al., 2017). Then, 1/3 cup of briquette mixture was placed inside the pasta manual press for pressure to be exerted (Video Eppo, 2017). After the briquette mixture was molded, the briquettes were left to dry for one week before physical and combustion tests (Withatanang et al., 2017).

Figure 4

Briquette production

Density

A ruler and weighing scale were used to measure the dimensions of each briquette, and then, the gathered measurements were inputted in the density formula from Aliyu et al. (2020) (Figure 5):

$$Density = \frac{m}{\pi r^2 h}$$

Where:

m = mass

r = radius of the briquette

h = height of briquette

Figure 5

Density test

Burning Rate

Before the duration of the burning rate test, it was ensured that the test would be done in a closed, clean, and tidy area which was free of flammable and combustible materials. The researchers identified possible fire hazards in the area and assured to prevent conducting the test near them (e.g., electrical circuits). Moreover, fire extinguishers were readily at hand in emergencies (Scottish Fire Rescue Service, 2020). Lastly, the researchers wore masks during the combustion processes and used tongs and mittens to avoid getting burned when handling the briquettes.

The mass of each briquette was measured using a weighing scale before it was burned for 1 minute. After it was burned for 1 minute, its mass was measured again (Figure 6). The results gathered were then inputted in the formula (Mohammed & Olugbade, 2015):

$$Burning\ Rate = \frac{Q1-Q2}{T}$$

Where:

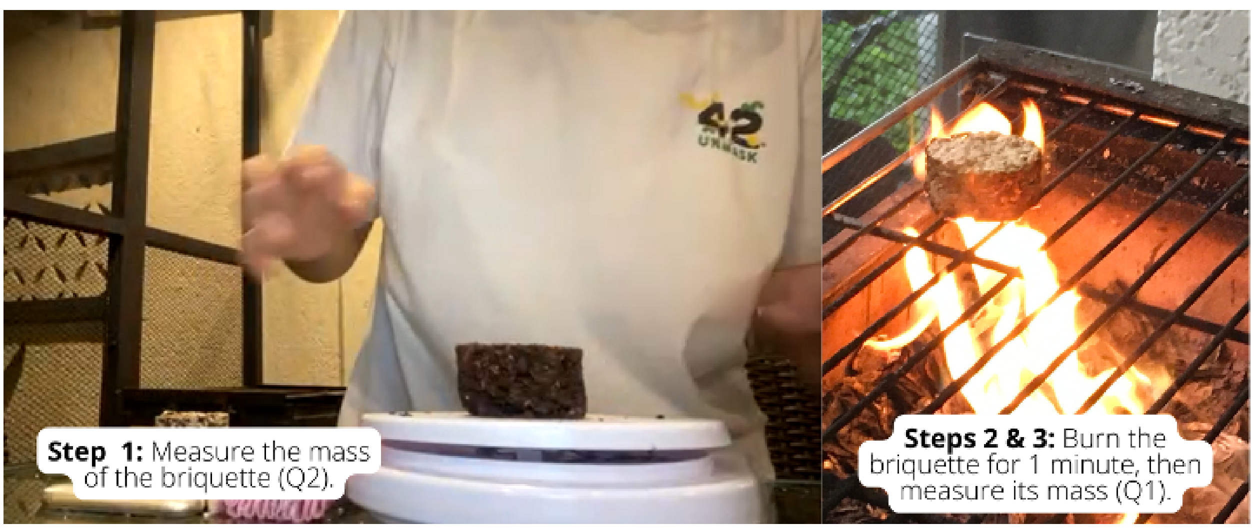
Q1 = mass of the briquette after being burned for 1 minute

Q2 = initial mass of the briquette

T = burning time

Figure 6

Burning rate test

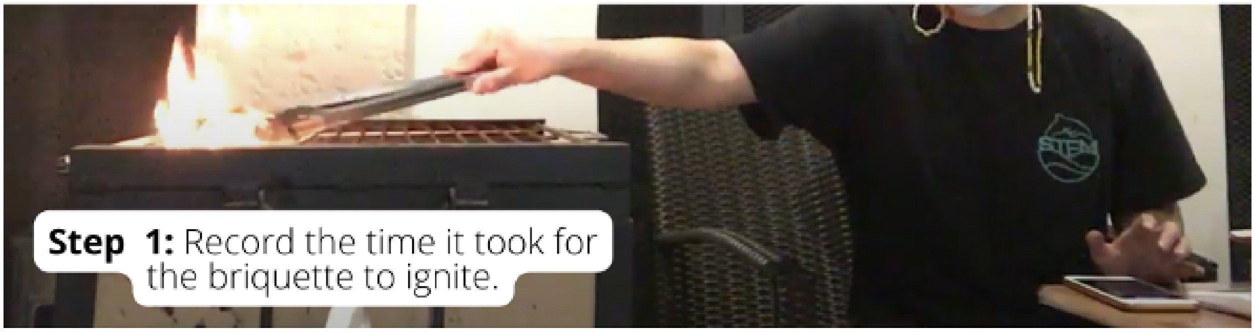


Ignition Time

Before the duration of this test, the same safety precautions implemented for the burning rate test were followed. For ignition time (Figure 7), the time it took for each briquette to smoke up or show a bright lit flame (signs of burning) was recorded using a timer (Kabok et al., 2018).

Figure 7

Ignition time test

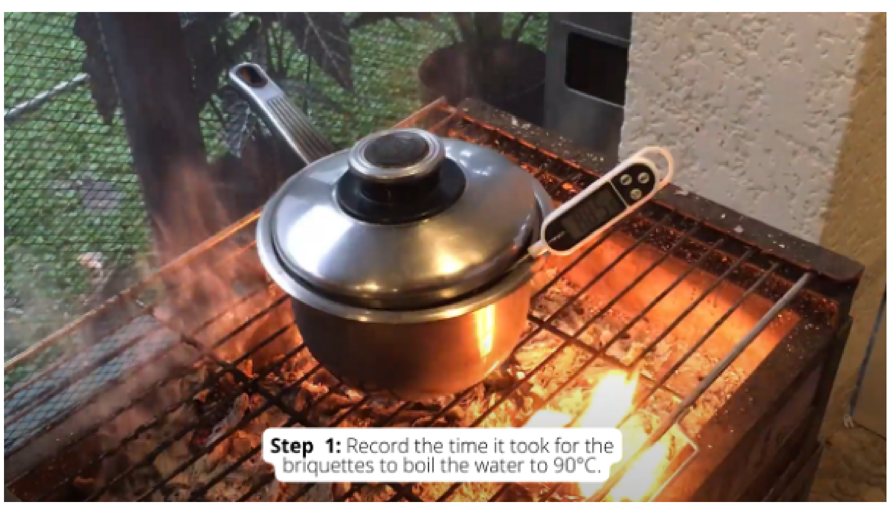


Efficiency

The same as previous tests discussed, the same safety precautions implemented for the burning rate test and ignition time were followed. As seen in Figure 8, 5 briquettes per briquette group were set on fire to boil 250 ml of water. Then, the time it took for the briquettes to boil the water until it reached 90°C was recorded using a timer (Ikelle & Ivoms, 2014).

Figure 7

Ignition time test



Statistical Treatment

The data gathered from the four measurement parameters (dependent variables) were organized and analyzed by utilizing statistical treatments such as Descriptive Statistics, One-Way ANOVA with a Post-Hoc test of Tukey's HSD, and MANOVA. Descriptive statistics was used to ascertain and examine the effectiveness of each briquette group by utilizing five samples for each test to determine the results on a selected combustion characteristic. One-Way Analysis of Variance (One-Way ANOVA) was performed using Jamovi. It was used to see if the mean of the dependent variable parameters differed significantly pending on the different briquettes produced. If the results of the p-value were more significant than 0.05, the Post-Hoc test Tukey's Test of Honest Significant Difference (Tukey's HSD) was conducted using Jamovi to measure and determine the differences in the group's results. Lastly, One-Way Multivariate Analysis of Variance (One-Way MANOVA) was used to check whether the difference between the independent and dependent variables is statistically significant.

RESULTS AND DISCUSSION

Density

Table 1

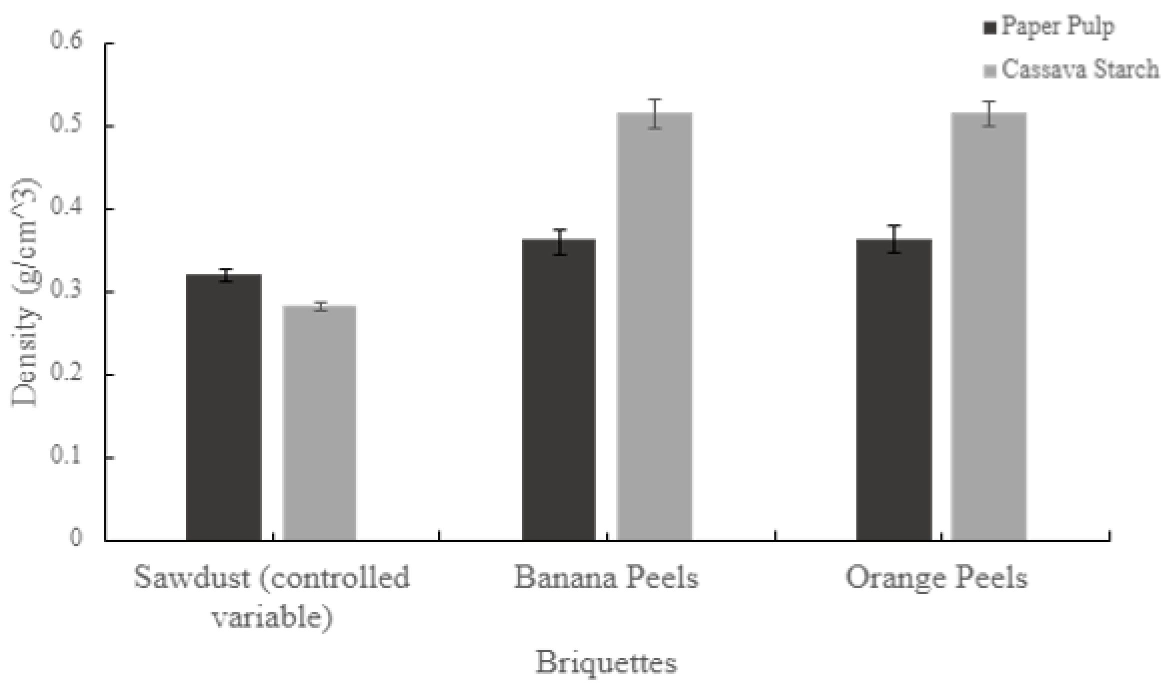
Density: Group Descriptive Statistics of the Six Briquette Groups

	Briquettes	*N*	*Mean*	*SD*	*SE*
Density	Sawdust and Paper	5	0.319	0.00789	0.00353
	Sawdust and Cassava	5	0.282	0.00620	0.00277
	Banana and Paper	5	0.362	0.01206	0.00539
	Banana and Cassava	5	0.515	0.01833	0.00820
	Orange and Paper	5	0.333	0.01670	0.00747
	Orange and Cassava	5	0.583	0.01555	0.00695

For the density test conducted, 30 briquettes were examined where 5 samples were tested per group. Based on the density results (Table 1), briquettes composed of orange peels and cassava starch attained the highest average density (M=0.583 , SD=0.01555). Orange peels and cassava starch have a natural thick density than other materials tested in this group. Meanwhile, briquettes out of sawdust and cassava starch (M=0.282 , SD=0.00620) attained the lowest average density. Although cassava starch added some density to the briquette, sawdust brings little to no density to the briquette.

Figure 9

Average Densities of Briquettes Made of Sawdust (controlled variable), Banana Peels, and Orange Peels



As seen in Figure 9, the researcher's base intervention (banana and orange peels) mixed with cassava starch as the binder produced the briquette with the highest computed densities. Meanwhile, the controlled variable briquettes (sawdust & paper, and sawdust & cassava) had the lowest densities.

The results on density reveal that the two variables influencing the high density of the briquettes were those groups that contained cassava starch as a binder or orange peels as a base. A similar study by Sen et al. (2016) aligns with the results gathered since the cassava starch gel briquettes also yielded a high density. The highest average density among the briquette groups was made of orange peels & cassava starch (M=0.583 , SD=0.01555). Furthermore, Aliyu et al. (2020) also stated that briquettes made with orange peels obtained the highest density.

Khan (2017) said, "If the volume increases, then the density will decrease since density is inversely proportional to volume." The briquettes made of orange peels and cassava starch had the shortest radius, which led to a lower volume and higher density. According to Davies and Davies (2013), the higher the density of the briquette, the more energy it can release. The groups of briquettes that yielded the lowest densities were those made with sawdust & paper (M=0.319 , SD=0.00789) as well as sawdust & cassava starch (M=0.282 , SD=0.00620). A similar study by Thulu et al. (2016) experimented on waste paper & sawdust briquettes that attained the lowest density.

Table 2

Fisher's One-Way ANOVA of the Density of Briquettes

	F	***df1***	***df2***	***p***
Density	397	5	24	<.001

Based on the Shapiro-Wilk Normality Test, the data is normal since $p>0.05$ ($p=0.777$). Thus, the data is normally distributed and accurate. In addition, the variables also have equal variances since the p-value attained in Levene's Homogeneity of Variances Test is greater than 0.05 ($p=0.453$). The data gathered in the One-Way ANOVA conducted (Table 2) shows that the p-value is significant, $F(5, 24)=397$, $p<0.05$.

Table 3

Tukey Post-Hoc Test on Density of Briquettes

		Sawdust and Paper	***Sawdust and Cassava***	***Banana and Paper***	***Banana and Cassava***	***Orange and Paper***	***Orange and Cassava***
Sawdust and Paper	Mean difference	—	0.0374 **	-0.0426 ***	-0.196 ***	-0.0136	-0.2634 ***
	p-value	—	0.003	< .001	< .001	0.615	< .001
Sawdust and Cassava	Mean difference	—	—	-0.0800 ***	-0.233 ***	-0.0510 ***	-0.3008 ***
	p-value	—	—	< .001	< .001	< .001	< .001
Banana and Paper	Mean difference	—	—	—	-0.153 ***	0.0290 *	-0.2208 ***
	p-value	—	—	—	< .001	0.026	< .001
Banana and Cassava	Mean difference	—	—	—	—	0.1820 ***	-0.0678 ***
	p-value	—	—	—	—	< .001	< .001
Orange and Paper	Mean difference	—	—	—	—	—	-0.2498 ***
	p-value	—	—	—	—	—	< .001
Orange and Cassava	Mean difference	—	—	—	—	—	—
	p-value	—	—	—	—	—	—

*Note. * p < .05, ** p < .01, *** p < .001*

The Post-Hoc Test results (Table 3) show that the p-values with a value less than 0.05 are significant. Thus, there are significant differences between the following groups:

A. sawdust & paper pulp and sawdust & cassava starch($p<0.05$)
B. sawdust & paper pulp and banana peels & paper pulp ($p<0.05$)
C. sawdust & paper pulp and banana peels & cassava starch ($p<0.05$)

D. sawdust & paper pulp and orange peels & cassava starch ($p<0.05$)

E. sawdust & cassava starch and banana peels & paper pulp ($p<0.05$)

F. sawdust & cassava starch and banana peels & cassava starch ($p<0.05$)

G. sawdust & cassava starch and orange peels & paper pulp ($p<0.05$)

H. sawdust & cassava starch and orange peels & cassava starch ($p<0.05$)

I. banana peels & paper pulp and banana peels & cassava starch ($p<0.05$)

J. banana peels & paper pulp and orange peels & paper pulp ($p<0.05$)

K. banana peels & paper pulp and orange peels & cassava starch ($p<0.05$)

L. banana peels & cassava starch and orange peels & paper pulp ($p<0.05$)

M. banana peels & cassava starch and orange peels & cassava starch ($p<0.05$)

N. orange peels & paper pulp and orange peels & cassava starch ($p<0.05$)

Burning Rate

Table 4

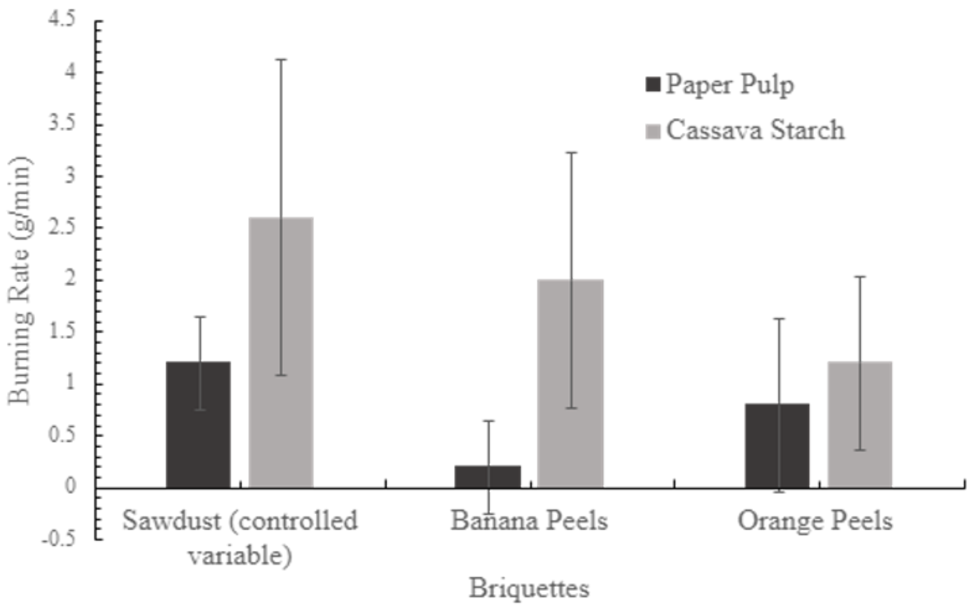
Burning Rate: Mean, Standard Deviation, and Standard Error of the Six Briquette Groups

	Briquettes	***N***	***Mean***	***SD***	***SE***
Burning Rate	Sawdust and Paper	5	1.200	0.447	0.200
	Sawdust and Cassava	5	2.600	1.517	0.678
	Banana and Paper	5	0.200	0.447	0.200
	Banana and Cassava	5	2.000	1.225	0.548
	Orange and Paper	5	0.800	0.837	0.374
	Orange and Cassava	5	1.200	0.837	0.374

In Table 4, among the 30 briquette samples used to test burning rate (where 5 briquettes were also tested per group), briquettes composed of sawdust and cassava starch lost the most amount of grams per minute ($M=2.600$, $SD=1.517$), while banana and paper pulp briquettes ($M=0.200$, $SD=0.447$) lost the least amount of grams per minute.

Figure 10

Average Burning Rates of Briquette Made of Sawdust (controlled variable), Banana Peels, and Orange Peels



Based on Figure 10, it is observed that the briquette groups made with cassava starch binder are the top three briquettes groups that lost the most mass. On the other hand, the briquettes out of paper pulp are the bottom three briquette groups that lost the least weight.

Table 4 shows that the briquettes made with sawdust & cassava starch (M=2.600 , SD=1.517) yielded the highest burning rate. Thus, the use of cassava starch binder yields a high burning rate for briquettes. A study by Senchi and Kofa (2020) resulted in cassava starch-bound briquettes with high burning rate values ranging from 16.26 to 20.76.

High burning rates imply that the briquettes can quickly run out, thus serving as a fuel source for a short period. Hence, briquettes out of sawdust & cassava starch degrade the fastest among the other briquettes. According to Nazari et al. (2015), briquettes with low burning rates are more effective since these can serve as a fuel source for an extended period. Therefore, the briquettes made out of banana peels & paper pulp are the most effective group since they attained the lowest burning rate. This type of briquette attained the most effective burning rate due to the presence of paper pulp. Nordquist (2019) stated that flammable materials such as paper contribute to good combustion characteristics of the briquettes. Karimibavani et al. (2020) stated that the denser the briquette, the more energy is released, and the denser the briquette. Hence, the expected result is briquettes made of orange peels & cassava starch would have the highest burning rate since they attained the highest density in the previous test. However, it was seen that sawdust and cassava starch briquettes had the highest burning rate; hence sawdust is the factor that affected the results the most.

Tamilvanan (2013) stated that the presence of sawdust influences the increase in the burning rate. Therefore, it is a factor that influenced the high burning rate of the sawdust & cassava starch briquette group. In addition, this is also proven by a study by Thulu et al. (2016) where their study involved briquettes made of banana peels & sawdust and their results showed that those briquettes attained a high burning rate (2.52) due to the presence of sawdust. Hence, the use of sawdust on briquettes greatly influences the burning rate of the briquettes.

Table 5

Fisher's One-Way ANOVA of the Burning Rate of Briquettes

	F	***df1***	***df2***	***p***
Burning Rate	3.91	5	24	0.010

Based on the Shapiro-Wilk Normality Test, the data is normal for burning rate since $p>0.05$ ($p=0.174$). Thus, the data is normally distributed and accurate. In addition, the variables also have equal variances since the p-value attained in Levene's Homogeneity of Variances Test is greater than 0.05 ($p=0.254$). The data gathered in the One-Way ANOVA conducted (Table 5) shows that the p-value is significant, $F(5, 24)=3.91$, $p<0.05$. Thus, the Post-Hoc Test using Tukey's HSD has been used to determine which among the briquette groups shows a significant difference in terms of burning rate.

Table 6

Tukey Post-Hoc Test on Burning Rate of Briquettes

		Sawdust and Paper	***Sawdust and Cassava***	***Banana and Paper***	***Banana and Cassava***	***Orange and Paper***	***Orange and Cassava***
Sawdust and Paper	Mean difference	—	-1.40	1.00	-0.800	0.400	0.000
	p-value	—	0.236	0.584	0.777	0.985	1.000
Sawdust and Cassava	Mean difference	—	—	2.40**	0.600	1.800	1.400
	p-value	—	—	0.007	0.919	0.068	0.236
Banana and Paper	Mean difference	—	—	—	-1.800	-0.600	-1.000
	p-value	—	—	—	0.068	0.919	0.584
Banana and Cassava	Mean difference	—	—	—	—	1.200	0.800
	p-value	—	—	—	—	0.391	0.777
Orange and Paper	Mean difference	—	—	—	—	—	-0.400
	p-value	—	—	—	—	—	0.985
Orange and Cassava	Mean difference	—	—	—	—	—	—
	p-value	—	—	—	—	—	—

Note. * $p < .05$, ** $p < .01$, *** $p < .001$

The results of the Post-Hoc Test (Table 6) show that the p-values with a value less than 0.05 are significant. Thus, significant differences lie between the following groups:

A. sawdust & cassava starch and banana peels & paper pulp ($p<0.05$)

B. sawdust & cassava starch and orange peels & paper pulp ($p<0.05$)

C. sawdust & cassava starch and orange peels & cassava starch ($p<0.05$)

D. banana peels & paper pulp and banana peels & cassava starch ($p<0.05$)

Ignition Time

Table 7

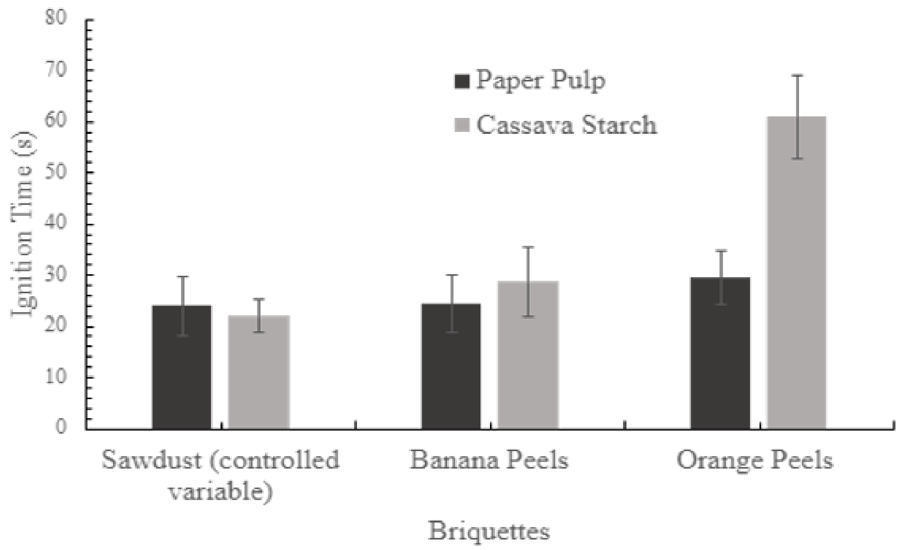
Ignition Time: Group Descriptives of the Six Briquette Groups

	Briquettes	*N*	*Mean*	*SD*	*SE*
Ignition Time	Sawdust and Paper	5	24.0	5.68	2.54
	Sawdust and Cassava	5	22.0	3.25	1.45
	Banana and Paper	5	24.4	5.50	2.46
	Banana and Cassava	5	28.7	6.79	3.04
	Orange and Paper	5	29.5	5.15	2.30
	Orange and Cassava	5	60.9	8.10	3.62

For the ignition time test, five briquettes per briquette group were also used for the test. Sawdust and cassava starch briquettes achieved the fastest average ignition time (M=22.0 sec, SD=3.25 sec). The sawdust in the briquette made it possible for the briquette to burn faster than the other briquettes tested in the group. On the other hand, orange and cassava starch briquettes (M=60.9 sec, SD=8.10 sec) took the longest time to ignite (Table 7). The orange peels, although dried, have properties that make the orange peels harder to ignite, thus having the longest average time in the group.

Figure 11

Average Ignition Times of Briquette Made of Sawdust (controlled variable), Banana Peels, and Orange Peels



According to Figure 11, it is recognized that the controlled variable briquettes (sawdust & paper briquettes, and sawdust & cassava briquettes) were the briquettes that took the fastest to ignite. The briquette groups made out of orange peels were the briquettes that took the longest to ignite.

Based on efficiency results (Table 12), briquettes made from banana & paper pulp had the highest efficiency (M=716.460), thus the reason for its low ignition time (M=24.4 , SD=5.50). Meanwhile, briquettes made of sawdust achieved the lowest ignition times due to the presence of sawdust (M=22.0 , SD=3.25 & M=24.0 , SD=5.68). These results are parallel to a study by Thulu et al. (2016), where their briquettes made out of sawdust and waste paper yielded the lowest ignition time. Moreover, it was stated by Kabok et al. (2018) that the lower the density of the briquettes, the faster the briquettes could ignite. The low density (Table 1) of the briquette groups made of sawdust (sawdust and cassava starch & sawdust and paper pulp) resulted in its quick ignition time.

According to Wei et al. (2020), pyrolysis is when biomass macromolecules break down into smaller molecules undergoing high temperatures. This increases the kinetic energy, resulting in the briquette's ignition. Orange peels have slow pyrolysis (Zanella et al., 2016). Hence, it took longer for the briquettes made of orange peels and cassava starch to ignite since the kinetic energy was lower. In addition, the briquette group of orange peels & cassava starch yielded the The highest density (Table 1) also influenced the long ignition time (Kabok et al., 2018). Moreover, Gbabo et al. (2018) stated that the ignition time increased when a high proportion of binder was used in the briquettes. Thus, a possible factor in the long ignition time of orange peels and cassava starch briquettes came from the use of a 70:30 (binder: base) ratio in creating the briquettes.

El-Haggar (2007) stated that the briquettes could expand or shrink during the drying process. Therefore it was expected that the briquettes of the orange & cassava starch group's briquettes would shrink. The orange and cassava briquette group also had a mean of 60.9 seconds, being exceptionally long since it is nearly double the other briquettes' ignition time. A probable reason for this result is caused by its evident shrinkage during the briquette drying process.

Table 8

Fisher's One-Way ANOVA of the Ignition Time of Briquettes

	F	***df1***	***df2***	***p***
Ignition Time	30.4	5	24	<.001

Based on the Shapiro Wilk Normality Test, the data is normal for ignition time since $p>0.05$ ($p=0.108$). Thus, the data is normally distributed and accurate. In addition, the variables also have equal variances since the p-value attained in Levene's Homogeneity of Variances Test is greater than 0.05 ($p=4.15$). The data gathered in the One-Way ANOVA conducted (Table 8) shows that the p-value is significant, $F(5, 24)=1.22E-09$, $p<0.05$. Thus, the Post-Hoc Test using Tukey's HSD was used to determine which among the briquette groups showed a significant difference in ignition time.

Table 9

Tukey Post-Hoc Test on Ignition Time of Briquettes

		Sawdust and Paper	*Sawdust and Cassava*	*Banana and Paper*	*Banana and Cassava*	*Orange and Paper*	*Orange and Cassava*
Sawdust and Paper	Mean difference	—	2.02	-0.418	-4.72	-5.480	-36.9***s
	p-value	—	0.994	1.000	0.804	0.692	< .001
Sawdust and Cassava	Mean difference	—	—	2.440	-6.74	-7.502	-38.9***
	p-value	—	—	0.986	0.487	0.372	< .001
Banana and Paper	Mean difference	—	—	—	-4.30	-5.062	-36.5***
	p-value	—	—	—	0.857	0.756	< .001
Banana and Cassava	Mean difference	—	—	—	—	-0.760	-32.2***
	p-value	—	—	—	—	1.000	<.001
Orange and Paper	Mean difference	—	—	—	—	—	-31.4***
	p-value	—	—	—	—	—	< .001
Orange and Cassava	Mean difference	—	—	—	—	—	—
	p-value	—	—	—	—	—	—

Note. * p < .05, ** p < .01, *** p < .001

The Post-Hoc Test results (Table 9) show that the p-values with a value less than 0.05 are significant. Hence, shows that significant differences lie between the following groups:

A. sawdust & paper pulp and orange peels & cassava starch ($p<0.05$)
B. sawdust & cassava starch and orange peels & cassava starch ($p<0.05$)
C. banana peels & paper pulp and orange peels & cassava starch ($p<0.05$)

D. banana peels & cassava starch and orange peels & cassava starch ($p<0.05$)

E. orange peels & paper pulp and orange peels & cassava starch ($p<0.05$)

Significant Differences Between Density, Burning Rate, and Ignition Time Variables

Table 10

Multivariate Tests on Density, Burning Rate, and Ignition Time (Dependent Variables)

		value	*F*	*df1*	*df2*	*p*
Briquettes	Pillai's Trace	5	24.0	5.68	2.54	<.001
	Wilks' Lambda	5	22.0	3.25	1.45	<.001
	Hotelling's Trace	5	24.4	5.50	2.46	<.001
	Roy's Largest Root	5	60.9	8.10	3.62	<.001

Table 11

Univariate Tests on Density, Burning Rate, and Ignition Time (Dependent Variables)

	Dependent Variable	*Sum of Squares*	*df*	*Mean Square*	*F*	*p*
Briquettes	Density	0.36494	5	0.0730	397.04	<.001
	Burning Rate (g/min)	18.26667	5	0.0730	3.91	0.010
	Ignition Time	5357.79944	5	1071.5599	30.41	<.001
Residuals	Density	0.00441	24	1.84e-4		
	Burning Rate (g/min)	22.40000	24	0.9333		
	Ignition Time	845.67568	24	35.2365		

The multivariate test results (Table 10) among the conducted tests (density, efficiency, burning rate, and ignition time) show that the p-value is statistically significant, Wilks' Λ=0.002 F(15.000, 61.134)=35.625, $p<0.001$. Moreover, the results of the univariate tests (Table 11) show that the p-values of density, burning rate, and ignition time are significant as well ($p<0.05$).

Efficiency

Table 12

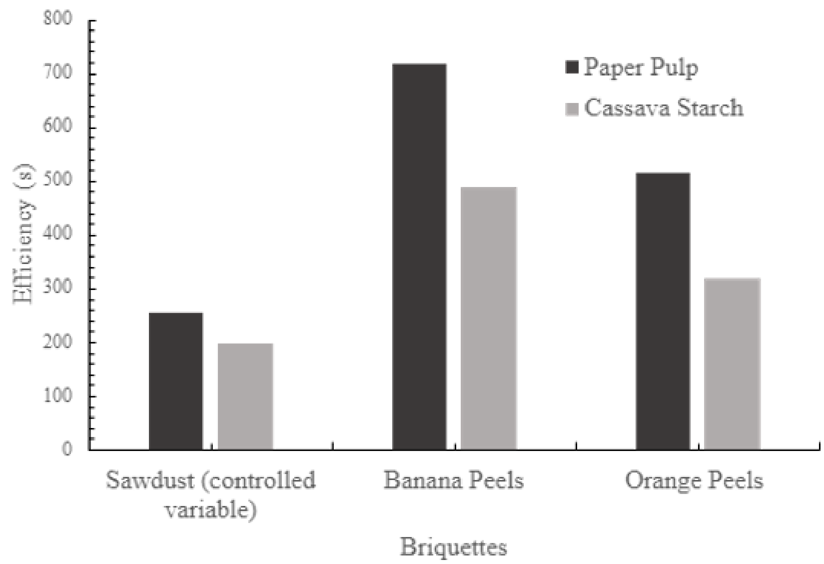
Efficiency: Group Descriptives of the Six Briquette Groups

	Briquettes	***N***	***Mean***
Efficiency	Sawdust and Paper	1	255.126
	Sawdust and Cassava	1	196.992
	Banana and Paper	1	716.460
	Banana and Cassava	1	487.905
	Orange and Paper	1	514.811
	Orange and Cassava	1	319.220

The Water Boiling Test (WBT) used five samples per briquette group to test the efficiency of the briquettes. The sawdust and cassava starch group acquired the fastest average time (M=196.992) while briquettes out of banana and paper pulp (M=716.460) attained the longest average time to boil the water (Table 12). The sawdust and cassava starch group have greater burning properties than other materials in the group. The banana and paper pulp group took the longest because the banana peels have natural non-burning properties.

Figure 12

Average Efficiency Times of Briquette Made of Sawdust (controlled variable), Banana Peels, and Orange Peels



In Figure 12, the controlled variables (sawdust & paper briquettes, and sawdust & cassava briquettes) were the groups that we're able to heat the water to 90 °C the quickest. Contrarily, the briquettes made out of the base intervention (banana and orange peels) bound with paper pulp took the longest to boil the water.

As support, a study conducted by Davies et al.. (2017) revealed that sawdust and cassava starch briquettes had the fastest boiling time. Furthermore, in a study by Thulu et al. (2016), the results concluded that the briquettes made of sawdust & banana peels had the shortest boiling time in boiling water. This further proves the researchers' results to be accurate.

On the other hand, a study conducted by Oyelaran et al. (2015) concluded that the briquettes made of 85% paper pulp only took 17 minutes to boil water and had the fastest boiling time. Ignition time and efficiency (WBT) are positively correlated (Davies et al., 2017). The briquettes containing orange & cassava starch were expected to take the longest to boil the water because they took the longest to ignite (Table 7). Despite this, it was the third-fastest briquette group when it came to boiling the water (Table 12). However, the researchers have concluded that the most efficient briquettes were the ones made of sawdust & cassava starch because they boiled water the fastest.

CONCLUSIONS

The study indicates that the orange and cassava starch briquette is suitable for storage and transportation. While the briquette formed out of banana peels and paper pulp is the most effective and beneficial because it reaches optimization in the shortest period. The sawdust and cassava starch briquette are the most efficient, as they attain the fastest water boiling time. This paper adds to the current understanding of alternative and sustainable energy, especially briquette manufacturing, by giving data on density, burning rate, ignition time, and efficiency. To summarize, the developed briquettes are potentially utilized as fuel in remote rural areas. Its manufacturing could aid in intervening and alleviating environmental issues caused by excess food waste and the negative consequences of using it as unsustainable fuel. It is recommended to conduct further studies on improving production and operation aspects using different material ratios per briquette and examine the ash content, volatile matter, calorific matter, and chemical composition of the briquettes.

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