Development and Characterization of Briquettes made from Unsalable Banana Peel Wastes: A Preliminary Evaluation

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Development and Characterization of Briquettes made from Unsalable Banana Peel Wastes: A Preliminary Evaluation

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Abstract: *This study aims to evaluate and characterize the potential use of bio-briquette made from banana peel waste as an alternative energy source. For the binding and mixing procedures, the study used three treatments utilizing banana starch as binder agent at predetermined proportions. During the evaluation and characterization, it was found that the moisture content ranges from 71% to 75% and there was no significance difference (P-Value=1). The compressive strength of the briquettes produced ranges from 38.01 MPa to 38.39 MPa. Furthermore, the ignition time were 14.79±0.51s, 16.95±1.07s and 18.78±0.03s and there was no significance difference (P-Value=1). Additionally, the fracturability were 9.8±1.78, 14.00±1.63 and 14.90± 1.66 and there was no significance difference (P-Value=1). The result shows that developed bio-briquettes using banana wastes are potential for production and utilization and can replace the existing and available renewable energy sources in the market. The developed briquettes are suitable for domestic and industrial use.*

Keywords: Bio-briquettes; Agricultural Wastes; Briquetting; Bindering; Densification

1. INTRODUCTION

In this current day and age, the world is undergoing an increase of energy demand due to surmounting population. Utilizing renewable energy consumption will help to alleviate energy poverty while also reducing potential greenhouse gas emissions [1]. The bio-briquette serves a crucial role for adding another source for alternative energy supply. Renewable energy is generally defined as energy derived from energy resources that are naturally replenished within the human timescale [2]. In addition, bio-briquette is a good avenue that enables to not merely rely on fossil fuel and mitigate climate change by providing renewable and sustainable energy. In the Philippines, the country is rich in natural resources including fruits and vegetables. Banana is an important cash crop and commonly found in the country. The banana peels are left unused in the dump side after the body is taken for the utilization for starch making. The banana waste has a low economic value or a residual material after the main parts of this product is taken for use. Converting wastes as a residual material into fuel as a bio-briquette can make this material economically more profitable. Utilization of these materials as a source of alternative energy, particularly converting it into densified material or briquettes will add value to the product and at the same time address the problem of waste disposal [3].

The process used in changing these waste materials into bio-briquettes is called densification. Densification is a process of densifying and compacting the material by applying pressure into it, converting the material such as the biomass in loose for into a form that is high in density, uniform shape, low moisture content and increase in energy content [4, 5]. The process can help raise the calorific value of the material by means of reducing its volatile matter and becomes a stable fuel that is easy to transport and store while still reducing emissions [4]. Additionally, the banana peelings possess the high dry matter base and high value combustible fuel, which qualify it as alternative to firewood and charcoal for domestic and industrial energy- study of combustion [6]. The high heating value and energy density provide a good combustibility of the briquettes [7]. The bonding mechanism of a binder agent used to bind the briquettes is also important in determining its quality. Binder agent or "binder" which can be a partially decomposed fibrous organic material in order to release the fiber needed to physically hold the briquettes together [5].

Furthermore, the advantages of banana wastes are its continued availability because the banana plants are produced in a sustainable manner. In this research, banana tree wastes consisting of banana peels to be the components for briquette production. The potential of dried banana peel into as alternative bio-briquettes would be beneficial to the country as a means of reducing energy costs. This is predominantly because source is readily available locally and essentially a more economical basis of fuel as they are derivatives from agro-industrial processes. The difference of this research compared to any other from previous studies is the combination of the dried banana peels and banana starch in producing a single briquette. The wastes are to be mixed up in a proposed mold shape, to form a decent commercial briquette product.

2. MATERIALS

The descriptions, functions and materials used in the fabrication of briquettes made from banana peels and banana starch are shown in table 1.

3. METHODS

This chapter discussed about the development process, characterization of fuel briquette. Figure 1 depicts the process flow for the production of banana peels briquettes.

3.1 Preparation of Materials

Cleaning: Collection of the wastes followed by cleaning and sorting was done to remove impurities from the biomass such as metal, plastic strings, dirt, soil, etc.

Foreign materials affect the performance of machines during processing as well as the quality produced [8].

Fig. 2. Biomass Preparation for Briquetting

Table 1. Description and Functions of Materials

Materials	Description and Functions
Heavy Duty Blender	A highly efficient electric culinary appliance used to cut or chop food inside its container.
Oven Dryer	This machine is used to eliminate moisture by drying of heating the samples stored inside using the convection process.
Mixing bowl	This deep container is used to store or carry samples that are subject to mixing or processing.
Whisk	It is a kitchen utensil made of wire used for mixing and blending ingredients.
Measuring cup	This utensil is used to measure the volume of samples in different forms.
Hydraulic Press	This machine works by using piston as a pump to put pressure to the briquette samples inside the hopper.
Tray	A tool used for storage and carrying of samples.
Digital Weighing Scale	This device is used to measure the mass of a sample.
Stove	A heat-generating equipment used for cooking.
Ruler	A 12-inch long tool used to measure the length of samples.
Ladle	It is a cooking implement with a spoon-like structure used for mixing the sample.
Banana Peels	The skin of a banana fruit which is used as the main ingredient for the briquetting process.
Banana Starch	Consists of processed rejected bananas which are turned into a binding agent.

Storing: Proper storing of biomass is essential to allow natural drying to minimize the need of drying the material for a longer time just to achieve the required MC for the densification process. The piled raw material can be stored in building sheds or can be covered to avoid mixing with sand, stone, and other impurities [9].

Pre-drying: The process of reducing MC of biomass to the minimum required is essential to initiate the densification process. The acceptable moisture content should be between 5-15% [9]. The residues were oven-dried for 60ºC for 12 hours using cabinet drier (IPP1400eco, Memmert). The MC of materials should be reduced to the optimum level required for densification [9, 10].

Fig. 1. Process flow for the production of briquettes

3.2 Sizing Materials

Banana peels were collected from the farm dumps of TADECO Banana Plantation, Tagum City, Philippines. After the collection of materials, the dried banana peels were then powdered using heavy duty blender (EB-747A, E-Blender).

3.3 Adding of Binder Agent

The pan was preheated at low heat temperature. The cold water was added first in the mixing bowl while the banana starch was gradually added; then vigorously mixed and cooked until a desired consistency was achieved. Mixing of the materials was out for 5 min until the mixture became homogeneous and attained the uniform particle distribution and consistency. The produced mixture was unloaded from the mixing bowl to a container and keep until ready for densification. The percent binding agent was computed based on the dried biomass by weight prior to mixing and briquetting operation.

Table 2. Proportion of Briquettes Composition

Mixture		Proportion
Banana Peels (G)	Banana Starch (G)	
100	10	100:10
100	15	100:15
100	20	100:20

3.4 Mixing of Materials and Binder Agent

As shown in table 2 the proportion of briquettes composition. For the binding and mixing procedures, the banana starch and water serve as binding agents at an appropriate moisture content and predetermined proportions (100:10, 100:15, 100:20) were applied. It is more appropriate to use different ratio in binder agent; since there is still no existing study in briquettes using banana starch. This will help to determine the exact composition for a good outcome briquette.

3.5 Molding of Briquettes

The study utilized the existing hydraulic piston-type briquetting machine located in Department of Agricultural and Biosystems Engineering at Caraga State University. The prepared sample per mixture-proportion was feed in the hopper though the compressing cylinder. The machine will compress the biomass mixture after feeding at the hopper. The piston through the chamber and die will form the compressed into a cylindrical briquette. The piston will act as a pushing mechanism to initiate the compression and the compressed samples will pass from the chamber through the die in a briquette form [9, 11]. The briquettes were molded into a cylindrical shape with the length of 4-inch and width of 2-inch.

3.6 Drying of Briquettes

In addition, the initial weight of each briquette sample was determined and placed in an oven set at 103ºC for 24 hours. The samples were removed and cooled in a tray then reweighed [12]. The molded briquettes were air dried for 48 hours to achieve the desired moisture prior to testing and evaluation.

3.7 Characterization of Briquettes

The characterization of briquettes was conducted to determine the physical properties and chemical properties of the briquette produced using charcoal briquettes as standard.

3.7.1 Moisture content (MC)

Defined as the ratio of the mass of water in a sample of briquette before and after drying, expressed as a percentage. MC affects the combustion process where the heat produced used to evaporate the water first [9]. Furthermore, moisture content analysis involved a series of repeating the process of drying and weighing via a specific procedure. The moisture content was determined using Eq. (1) from [13].

$$\%MC = \left(\frac{m_b - m_a}{m_b}\right) * 100\% \qquad (1)$$

Where m_b is the mass of briquette immediately after compression and m_a is the mass of briquette after oven dry.

3.7.2 Ash Content (AC)

Defined as the mass of incombustible material remaining after burning a given briquette sample, expressed as a percentage. According to SNI No. 1/6235/2000 standard, the moisture content and ash content should be less than 8% and the volatile matter is less than 15% [10]. Higher value of AC shows lower Caloric Value, the harder it takes to combust. Ash content can be calculated under ASTM D-3174 2012 standard formulas as shown in Eq. (2) [11].

$$\%AC = \left(100 - \frac{W_0 - W}{W_{S0}}\right) * 100\% \qquad (2)$$

Where W_0 is sample and saucer weight before ashing (g), W is the weight of saucer and ash (g), and W_{S0} is sample weight before ashing (g).

3.7.3 Volatile Matter Content (VMC)

The unstable material that tends to not remain in one state and will rapidly transit to another state, or vaporize, expressed as a percentage. It is defined as substance that are lost when the sample is heated in a furnace for 7 minutes at $900°C$. The higher volatile content in bio-briquettes, the easier it combusts [9, 11]. High value of volatile matter can degrade briquette's quality because it lowers the content of fixed carbon, can also affect the calorific value produced, and it causes in increasing the amount of smoke produced from burning [10]. VM can be calculated using ASTM D-3175 2018 standard with the following formula Eq. (3) and Eq. (4) .

$$\%\ Lost\ Weight = A = \frac{(W_0 - W\ )}{(W_{S0})} * 100\% \qquad (3)$$

$$\%VM = Lost\ weight - MC * 100\% \qquad (4)$$

Where W_0 is sample weight and initial cup (g), W is the weight of cup and ash after heating (g), and Wso is the initial sample weight (g).

3.7.4 Fixed carbon (FC)

Defined as the level of fixed/bonded carbon contained in the briquettes, expressed as a percentage. The fixed carbon is the result of a reduction of 100% sample with volatile matter, moisture content and ash content. A higher level of carbon bound leads to an increase in its calorific value [9, 11]. The fixed carbon (FC) was determined using the data previously obtained in the proximate analysis (MC, VM, AC) and can be calculated using the Eq (5) [10]. The released moisture content is considered in the volatile matter percentage.

$$\%FC = 100 - (AC(\%) - VM\ (\%)) \qquad (5)$$

Where HV is the calorific value, FC is the percentage of fixed carbon content, and VM is the percentage of volatile matter.

3.7.5 Calorific Value (CV)

Calorific value i**s** known as heating value *(*HV*)* or energy value of a briquette. It is the amount of heat liberated per unit mass of the briquette and is measured using a bomb calorimeter. The calorific value shows the energy contained in a briquette. It is determined by measuring the heat produced by the complete combustion of a specified quantity of it, expressed in calorie per gram. This test was conducted to determine standard quality of the briquettes fuel power and determine the standard sale value of the briquettes [9] . Calorific values will be calculated using the fixed carbon content and volatile matter of the briquettes according to the method and Eq. (6) presented in [14].

$$\mathrm{HV} = (\mathrm{FC\%} + \mathrm{VM\%});\ \frac{\mathrm{kj}}{\mathrm{kg}} \qquad (6)$$

Where HV is the calorific value, FC is the percentage of fixed carbon content, and VM is the percentage of volatile matter.

3.7.6 Compressive Strength Test (CST)

Compressive strength test is defined as a mechanical test that measures the maximum amount of compressive load a briquette can bear before fracturing and can be calculated using Eq (7).

$$K^t = \left(\frac{P}{A}\right); \ kg/cm^2 \qquad (7)$$

Where: K^t is stress at failure (kg/cm^2), P is axial load at failure (kg) and A is cross-sectional area
(kg) and A is cross-sectional area (cm^2).

3.7.7 Bulk Density (BD)

The bulk density of a briquette is equal to mass per unit volume of the briquette and can be calculated using Eq (7):

$$\rho = \left(\frac{m}{v}\right); \ kg/cm^3 \qquad (8)$$

Where ρ is density of briquette (kg/cm^3), m is weight of briquette (kg) and V is volume of briquette (cm^3).

3.7.8 Fracturability

The bone-dried briquette samples were repeatedly dropped from a stationary starting point at 2-meter height into the concrete floor until it will be fractured. The number of drops taken for each briquette to fracture or disintegrate into pieces was recorded [15].

3.7.9 Ignition Time (IT)

The samples were ignited at the bottom and allowed to burn until it extinguished itself. The rate at which flame propagated was determined using stopwatch by the time taken in seconds

3.8 Statistical Analysis

The data was analyzed using the descriptive analysis such as the mean and standard deviation. Variance (ANOVA) then carried out to check the significant interaction between the performance parameters. A post hoc test using the least significant difference (LSD) test was applied to see any significant between the treatment means (binder proportion and mixture) used. $P \leq 0.05$ means that there is significant difference between test means. While $P \geq 0.05$ means that there is no significant difference between means. This analysis will focus on the descriptive statistics and correlational analysis of the various briquette quality.

Fig. 3. Data Analysis Procedures

4. RESULTS AND DISCUSSION

4.1 Population Size

A total of 40 bio-briquettes produced and utilized in this study for preliminary report. This was a good number to conduct all the initial analysis of parameters such that moisture content, compressive strength, ignition time and fracturability as shown in table 3 below.

Table 3. Sample Size of the Study

Parameter	Number of briquettes from each composition
Moisture Content (%)	10
Compressive Strength (MPa)	10
Fracturability	10
Ignition Time (s)	10

4.2 Moisture Content

Moisture content plays a vital role in different aspects of briquettes. The moisture content of briquettes affects most of its physical characteristics. Briquettes with lesser moisture content also manifest higher compressive strength because it promotes more compactability to the binder agent.

Table 4. Moisture Content Values of Developed Briquettes

Composition	n	Mean (%, wb)	Analysis of Variance Pr (> F)
T1	10	72.00 ± 3.00	1
T2	10	71.00 ± 2.00	
T3	10	75.00± 3.00	

As presented clearly in Table 4, the result of the t-test performed on the mean values of moisture content of fuel briquettes for each treatment. The approximate moisture content is 72%, 71% and 75%. It gives the impression that the treatments T1, T2, and T3 have standard deviation of 3.00, 2.00, and 3.00, respectively. It can be inferred that T1 and T3 have equal moisture content while T2 has the lowest moisture content attained after the drying process. The lower the moisture content, the higher its combustibility. Thus, T2 has a higher combustibility than the other treatment. Moreover, the statistical data gathered shows that there is no significant difference between the two treatments since P-value (1) is greater than the level of significance (0.05) hence null hypothesis is not rejected.

4.3 Compressive Strength

The compressive resistance test simulates the compressive stress due to weight of the top briquettes on the lower briquettes during storage in containers. The hardness of the produced briquettes was determined using universal testing machine. Compressive resistance of the densified products was determined by diametrical compression test. The flat surface of the briquette sample was placed on the horizontal metal plate of the machine.

Table 5. Compressive Strength Values

Composition	Mean (MPa)	Analysis of Variance Pr (> F)
T1	38.39 ± 0.52	0.99
T2	38.01 ± 0.76	
T3	38.29 ± 0.41	

As shown in Table 5, the mean of the sample per treatment during the compressive strength test. The compressive strength of the briquettes produced ranges

from 38.01 MPa to 38.39 MPa. The result shows that T1 has the highest mean of 38.39 MPa with a standard deviation of 0.52 MPa. It suggests that the first treatment with the least dense composition of binder agent could withstand the compressive test result more than the other treatments. This indicates that the binder agent plays a significant role in the compression and compaction of briquettes because it fills the void present in the briquettes. Thus, briquettes with the higher compressive strength value have a good quality and strong inter-particle bonds.
The statistical data obtained shows that there is no significant difference between the two treatments since P-value (1) is greater than the level of significance (0.05) hence null hypothesis is rejected. It demonstrates that they are potential to produce briquettes as fuel in several applications due to the fact that results from three treatments are not statistically the same. Additionally, the higher compressive strength the greater its durability and stability that is good for transportation and storage of briquettes.

4.4 Ignition Time

The ignition time was determined by igniting each briquette sample at the base in a drought free corner using Commando Safety matches. The time required for the flame to ignite the briquette, in seconds, was recorded as the ignition time and a used stop watch.

Table 6. Ignition Time Data

Composition	n	Mean (s)	Analysis of Variance Pr (> F)
T1	10	14.79 ± 0.51	
T2	10	16.95 ± 1.07	1
T3	10	18.77 ± 0.92	

As can be gleaned in Table 6, the mean ignition time of fuel briquettes for each treatment are presented. The approximate ignition time were 14.79s, 16.95s and 18.77s. It vividly shows that T1 has a lower mean value with the faster ignition rate. Moreover, it was also observed that the briquettes when ignited produced smoke but eventually vanished as the flame developed. It appears that the treatments T1, T2, and T3 has standard deviation of 0.51, 1.07, and 0.92 respectively.
The statistical data obtained shows that there is no significant difference between the two treatments since P-value (1) is greater than the level of significance (0.05) hence null hypothesis is rejected. And this clearly implies that the ignition time of three treatments fuel briquettes is not statistically the same.

4.5 Fracturability

The fracturability of the bio-briquettes was determined by dropping the samples repeatedly from a stationary starting point at 2-meter high into the concrete floor and counting the number of drops taken for each sample to fracture or disintegrate.

It can be inferred from Table 7 that T3 has a higher mean value compared to the remaining treatments or mixtures, namely T1 and T2. Thus, it implies that T3 samples have higher shatter resistance than the samples of T1 and T2. Also, this indicates that during the transportation, utilization, and storage, T3 has more ability to resist damage compared to the other treatment or mixture samples.

Table 7. Fracturability Values of the Samples

Composition	n	Mean	Analysis of Variance Pr (> F)
T1	10	9.80 ± 1.78	
T2	10	14.00 ± 1.63	1
T3	10	14.90 ± 1.66	

Furthermore, Table 7 presents the mean values for fracturability in every treatment along with the corresponding standard deviation. It appears that the treatments T1, T2, and T3 has standard deviation of 1.78, 1.63, and 1.66, respectively. The values for the standard deviation in each treatment seems too high. Thus, this result seems to support the presented huge values for coefficient of variance.
The statistical data gathered shows that there is no significant difference between the three treatments since P-value (1) is greater than the level of significance (0.05) hence null hypothesis is rejected. This implies that the fracturability of T1, T2, and T3 fuel briquettes are not statistically the same.

5. CONCLUSION

In the existing energy dilemma worldwide, it undergoes increase of energy demand due to the intensifying population. With the growing concern of climate change because of GHGs produced by fossil/coal fuel, the bio-briquette from agricultural wastes is a renewable energy that has a strong potential to be an alternative energy resource considering various factors, including the volume and the sustainability of wastes produced within the vicinity, initial cost, machine availability, and many more. It should also be less expensive or more efficient compared to the existing fossil/coal fuel for it to be called an effective replacement, and be able to compete in the market. Understanding the general concept of the production process, the basic quality testing parameters, and other considerations in briquetting paves the way for the development of a successful environmental-friendly, efficient, and cost-effective bio-briquettes.
Moreover, the quality of briquettes is characterized in terms of physical, mechanical, and thermal properties, depending on the measured parameters. It is also indicative of the effectiveness of the densification process and influences their ability to endure certain impacts because of handling, storage, and transportation. Furthermore, the banana peels using banana starch as binding agent fuel briquettes produced are environmentally friendly and sustainably ready that provide means to reduce desertification. The environmental implication and reduce health hazard associated with the use of fuel wood and charcoal. Therefore, combination of banana peels and banana starch provide good outcome that is good for domestic and industrial bio-briquette production.

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