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Utilization of *Jatropha* (*Jatropha curcas* L.) Wastes for Charcoal BriquettesCaezar A. CUARESMA^{*1}, Jessie C. ELAURIA^{*2}, Delfin C. SUMINISTRADO^{*2} and Marilyn M. ELAURIA^{*3}

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The study aims to determine the suitability of *Jatropha* (*Jatropha curcas* L.) wastes for charcoal briquette production. Three types of raw materials namely 100 % tuba-tuba husk, 50 % husk and 50 % pressed cake, and 100 % pressed cake were carbonized using FPRDI carbonizer. The carbonized materials were bonded with cassava and corn starch as binders at different binder level of 10 %, 14 % and 18 % based on the weight of feedstock to form charcoal briquettes. Sample briquettes were evaluated based on their charcoal yield, crushing strength, proximate analysis, and heating values. Variation of treatment means for VM, Ash content, fixed carbon crushing strength and heating values was highly significant.

Briquettes from pressed cake bonded with either cassava or corn starch at 10 %, 14 %, and 18 % was found to be superior among other materials tested. The 50 % J. husk and 50 % P. cake also showed promising results, but its quality may not be as good as that of pressed cake. The husk however, did not conform to the standards set by Philippine Standard Association (PHILSA), due to its high VM, and ash content. Based on the five properties, 10 % binder using pressed cake produced good *Jatropha* charcoal briquette.

Key Words

Biodiesel, Carbonizer, Briquette

1. Introduction

Energy has been generally considered as the core of the economic development strategies for the future. The increasing population and the rise of living standards, contribute to the increase in demand for energy in the world. However, most of the energy requirements of developing countries are still supplied by fossil-based fuel. Global environmental issues and exhaustion of fossil resources pose serious problems for energy consumption. It is in this context that other sources of energy such as geothermal, hydro-electric, coal, solar, wind and biomass are being tapped in the country.

Among the various biomass energy sources, seed oil-bearing crops have a potential as supplement for meeting the increasing requirements of petroleum and its

products. Biodiesel crops have a lot of scope to be planted in wasteland to meet out the increasing diesel demand apart from helping the farming community by creating rural employment and reducing the imports and air pollution. It has been discovered that the oil from *Jatropha* (*Jatropha curcas* L.) is an excellent diesel fuel substitute. *Jatropha* is locally known as tuba-tuba. It is a clean source of energy. One hectare *Jatropha* plantation with 4,400 plants per hectare under rainfed conditions can yield about 1,500 liters of oil (Ramesh D. *et al.* undated)¹⁾.

Transesterification technology is used to produce the biodiesel from *Jatropha* oil, which separates the glycerol from the raw *Jatropha* oil (Vyas, 2008)²⁾. The byproduct is an oilcake which cannot be used as animal feed due to its toxins viz., curcacin and cursin. The detoxified oilcake can be used as animal feed. However, this would entail additional cost for detoxification. The energy recovery from *Jatropha* oilcake has remained untapped.

Charcoal briquetting has been proposed as a viable recycling technology to treat the large tonnages of *Jatropha* wastes. Renewable energy technologies such as briquetting are useful for tapping energy from *Jatropha* wastes (Bisana and Laxamana, 1998)³⁾. The technology will play a vital role

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in the generation of energy for the future. The energy fuels from *Jatropha* wastes can be used for domestic electricity generation, thermal application for drying crops, cooking and lighting. It is for these reasons that the potential of *Jatropha* wastes for charcoal briquette was explored.

The main objective of the study was to determine the suitability of *Jatropha* (*Jatropha curcas L.*) wastes for charcoal briquette production. Specifically it aims: to determine the percentage charcoal yield of *Jatropha* wastes; to evaluate the physical properties of charcoal briquette in terms of its strength properties and to evaluate the chemical properties of charcoal briquettes based on the type of materials kind of binder and level of binder on the briquette's heating value (HV), volatile matter (VM), fixed carbon (FC) and ash content (AC).

2. Methodology

2.1 Carbonization and briquetting

Partially air dried *Jatropha* husks were collected and *Jatropha* husks were sorted out from the seeds and were placed in $1\text{ m} \times 1\text{ m} \times 15\text{ cm}$ trays for further sun drying. Initial moisture content (MC) of the husks was taken before carbonization.

Carbonization processes were conducted using the Forest Product Research and Development Institute (FPRDI) designed manual carbonizer (Fig. 1). This carbonizer has a capacity of 12 to 15 kg per hour feedstock depending on the moisture content of the materials. The carbonizer was designed to accommodate small materials such as wood chips, saw dust, baggasse, husk and hull. The flat plate can accommodate 0.1 cu.m feedstock depending on the bulk density to be carbonized. This has three major components, the hopper, flat plate bed and combustion chamber. It is a wood-fired manually operated, open type carbonizer made of mild steel plates and angular bars as support frame.

Fig. 1 Carbonization Process using FPRDI manual carbonizer

The combustion chamber has metal grill as grate bar. The materials are loaded on the hopper attached to the inclined bed or the pre-drying area of the carbonizer. The inclination provides additional drying and also serves as the waiting or transport area of the carbonizer. At the end of the inclined bed is the carbonization area where the combustion takes place. Under the carbonization area is where the burner fuels are located.

Jatropha husks were placed in the flat bed about 50 cm thick distributed along the length of the bed. About 2 kg wood fuel was used in firing the furnace. Carbonized materials were placed in airtight drums and were allowed to cool down for 24 hours.

The husk and pressed cake were briquetted using the FPRDI designed manual briquettor (Fig. 2). This equipment was used to convert charcoal fines with particle size passing 40 mesh produced from agro-forestry wastes to charcoal briquettes. The briquetting machine is a manually operated type with 20 B.I. pipes to produce uniform cylindrical briquettes. This briquettor has a capacity of 12 to 15 kg per hour of feedstock. The main components are the hopper, feeder, set of molds, cover plate and foot lever.

For the determination of percentage yield, three trials were conducted using 5 kg of *Jatropha* husks and pressed cake. The lump charcoal was reduced into fine particles using a metal mortar and pestle. The fine carbonized materials were then sieved and let passed through 20 mesh sieve.

A 3-factor-factorial experiment in Completely Randomized Design (CRD) was used to determine the effect of the type of material, type of binder and level of binder on the different parameters. Each of these factors has $3 \times 2 \times 3$ underlying levels. The complete design required $3 \times 2 \times 3 = 18$ number of runs and were replicated three times. In the experiment 10 %, 14 % and 18 % binder preparations were tried to determine its viability and the probable effect on

Fig. 2 The FPRDI Designed manual briquettor

the physical and chemical properties.

Prior to the briquetting operation, binder was prepared in gelatinized form by first boiling the water using a water heater. The mixture was stirred until a transparent solution was produced. The charcoal fines and gelatinized starch was poured into a mixing container and was mixed thoroughly by hand.

After thoroughly mixing the binder and the charcoal fines, the mixture was introduced to the briquettor. The mixture dropped directly to the molds or cavities and applied a force of 60 kg directly into the cylindrical molder which produced into uniform briquettes. The charcoal briquettes were placed in trays and dried directly under the sun for 2 to 3 days.

The percentage yield of the carbonized sample was determined based on its oven dry weight (Elauria, 2010)⁴⁾. A high percentage charcoal yield would indicate that the raw material is a promising source of charcoal. The following equation was used:

$$\% \text{ Charcoal Yield} = \frac{Wt_{\text{charcoal}}}{Wt_{\text{feedstock}}} \times 100 \quad (1)$$

2.2 Analysis of by-products

Samples of charcoal briquettes were analyzed for their heating values (HV), Volatile Matter (VM), fixed carbon (FC) and ash content (AC). Likewise, the crushing strength was determined using the universal testing machine (UTM).

2.2.1 Heating values (gross calorific values)

Determination of the heat of combustion (in gross calorific value) of charcoal briquettes was made with the Leco Automatic Calorimeter. The test methodology follows the ASTM D5865 "Standard Test Method for Gross Calorific Value of Coal and Coke" (www.astm.org/standards)⁵⁾.

2.2.2 Proximate chemical analysis

This analysis was made by heating the sample until it decomposes successively into three of the four complex items of the proximate analysis. The test laboratory was provided with a sample grinder, a muffle furnace with temperature control and indicating pyrometer, a thermostatically regulated drying oven, crucibles, desiccators jar, and analytical balances. The briquettes produced were analyzed for moisture content (MC), Volatile Matter (VM), ash content (AC), fixed carbon (FC) and heating value (HV) using Philippine Standard Association (PHILSA) 122:1976, PS No. 241:TM.01.1977 (PHILSA)⁶⁾.

1) Moisture Content

Samples were weighed and placed in the shallow crucibles in a $103 \pm 2^\circ\text{C}$ oven for three hours, then removed to a desiccator for cooling and reweighing. The percent

Fig. 3 Briquette being tested by Universal Testing Machine

moisture contained is the loss of weight of the sample divided by the net weight of the original sample in the crucible.

2) Volatile Combustible Matter

The samples were placed in deep crucibles with lids and weighed. These were inserted in a 900°C muffle furnace for 6 min, then removed, cooled in a desiccator and reweighed. The loss of weight of the sample in this instance is due to both moisture and volatile which were driven off. Moisture having been previously determined, volatile can be calculated on dry basis.

3) Ash Content

The three samples were heated in a 750°C oven for six hours, then removed, cooled in a desiccator, and reweighed. The percent ash content is the weight of the sample remaining divided by the net original weight.

4) Fixed Carbon

The percent fixed carbon is considered to be the difference between 100% and the sum of the percentages of volatile matter and ash content.

2.2.3 Crushing strength

The crushing strength of the sample briquette was determined using the Shimadzu Universal Testing machine (UTM). This test was done to determine the maximum allowable force that the sample briquette can withstand. The UTM was set at a speed/ stroke of 3 mm per min. and a load range of 0.2 ton force. The sample briquette was placed in upright position, and the force was applied axially (Fig. 3). Reading was taken after the sample briquette attained its maximum allowable force and collapsed.

3. Results and Discussion

3.1 Charcoal yield of jatropha husk and pressed cake

Table 1 presents the charcoal yield of Jatropha husk using the FPRDI manual carbonizer. The average yield of 43.44 % indicates that the raw material is a promising source of charcoal. The percentage yield based on 5 kg weight of pressed cake is also shown in Table 1. An average

Table 1 Percentage charcoal yield of *Jatropha* husk and pressed cake

Trials	Yield of <i>Jatropha</i> Husk (%)	Yield of Pressed Cake (%)
1	44.09	44.37
2	41.09	33.86
3	45.15	38.06
Average	43.44	38.76

Note: The yield was based on 5 kg weight of *Jatropha* husk per trial

of 38.76 % also revealed that this material is suitable and a promising source of charcoal. However, due to oil residue present in the pressed cake, the carbonization time was almost twice more rapid than the husk. Carbonization time of pressed cake and husk averaged at 10 min. and 18 min. per 5 kg, respectively. Carbonization process was monitored carefully to prevent the complete combustion of the material. Otherwise, ash will be produced instead of charcoal which is the desired material for the charcoal briquette.

3.1.1 Gross heating value

Gross heating value or calorific value is the

heat given out during combustion. It is measured by a calorimeter. Fig. 4 shows the gross calorific values of *Jatropha* briquettes bound with cassava and corn starch. *Jatropha* briquettes from 100 % Pressed Cake with either cassava or corn starch as binder produced the highest mean gross calorific values. The lowest gross calorific value was that of briquette from 100 % *Jatropha* husk. Analysis of Variance (ANOVA) results in Table 2 show that the heating value of *Jatropha* briquettes was significantly influenced by the material, type of binder and level of binder.

Further analysis using DMRT (Table 3) shows the effect of material, types of binder and level of binder on the gross heating value of *Jatropha* briquettes. The highest means was that of 100 % pressed cake bound with either cassava or corn at any level of binder. Comparing the means of material, the 100 % J. husk showed the lowest heating value followed by the combination of 50 % husk and 50 % pressed cake. The type of binder affects the heating value although their difference is small. The trend shows that when the binder level is increased, the heating value decreased. This trend applies to both cassava and corn as binders. However, in the case of 100 % husk bound with

Fig. 4 Gross heating values of *Jatropha* briquettes bound with cassava and corn at various binder level**Table 2** ANOVA on the Heating Value of charcoal briquettes from *Jatropha*

Source	DF	SS	MS	F-value
Material (A)	2	42488374.06	21244187	26732.6 **
Type of Binder (B)	1	25237.46	25237.46	31.76 **
AxB	2	59410.33	29705.17	37.38 **
Level of Binder C	2	31909.69	15954.84	20.08 **
AxC	4	116925.14	29231.28	36.78 **
BxC	2	327549.39	163774.7	206.09 **
AxBxC	4	667700.27	166925.07	210.05 **
Error	36	28608.9	794.69	
Total	53	43745715.25		

** Highly significant at $\alpha=0.01$

R² (%) 99.93, CV 0.74

Table 3 Effect of material, type of binder and level of binder on the HV of charcoal briquettes from *Jatropha*

Material	Type of Binder	Level of Bindera			Average of Material	Ave. Type of Binder
		10	14	18		
100 % Husk	Cassava	12238.2 d	11986.74 e	10465.73 g	11277.09	Cassava 15982.88
	Corn	9308.86 h	11311.03 f	12352.0 d		
50 % Husk	Cassava	16138.94 b	16047.86 bc	15923.34 c		
50 % P. Cake	Corn	16105.18 bc	16070.62 bc	15928.07 c		Corn
100 % P. Cake	Cassava	20383.74 a	20341.65 a	20319.89 a	20364.57	15802.01
	Corn	20454.45 a	20364.49 a	20323.24 a		
Average Level of Binder		3769.49	3828.97	3796.7		

^a Material x Type of Binder x Level of Binder, average of 3

Means marked with same letter in a column are not significantly different

corn as binder, as corn binder level increased, the heating value also increased. This is so because the heating value of corn at 14,536.89 J/g is a lot higher heating value than the heating value of J. husk at 11,996.78 J/g. Hence, when corn starch was used as binder in 100 % J. husk briquette, the heating value tends to increase when binder level was increased. In the case of cassava starch as binder in 100 % J. husk briquette, the heating value decreased as the level of cassava binder is increased. This is so because the ash content of 100 % J. husk briquette increased with the level of cassava binder hence reducing the heating value of 100 % J. husk briquette.

3.2 Proximate chemical analysis

The proximate chemical analysis of the briquettes included determining moisture content, volatile combustible matter, ash content and fixed carbon content.

3.2.1 Volatile matter (VM)

Volatile matter refers to the components of charcoal, except for moisture, which are liberated at high temperature in the absence of air. This is usually a mixture of short and

long chain hydrocarbons, aromatic hydrocarbons and some sulfur. As shown in Fig. 5, VM of briquettes from material using husk either 100 % J. husk bound or 50 % J. husk + 50 % pressed cake with either cassava or corn starch shows high as compared to 100 % pressed cake. Briquettes bound with either cassava or corn starch at 18 % binder level had the highest VM compared to briquettes with lower binder levels. This indicates that increasing the amount of binder tends to increase the VM of briquettes.

The Analysis of Variance on the VM of charcoal briquettes from *Jatropha* showed that material, type of binder and level of binder have a significant effect on the VM of *Jatropha* briquettes (Table 5). Further analysis using DMRT (Table 6) revealed that the VM differed with the type of binder used. Compared with briquette from 100 % pressed cake, VM of briquette from 100 % husk and 50 % husk and 50 % cake were much higher. This is very evident from the average VM of briquette from pure cake. This could be due to the high amount of residual liquid present in the 100 % J. husk briquette. However, variation of material with respect to level of binder from 14 % to 18 % binder

Fig. 5 VM of *Jatropha* charcoal briquettes bound with cassava and corn starch at various binder levels

Table 5 ANOVA on the VM of charcoal briquettes from Jatropha

Source	DF	SS	MS	F-value
Material (A)	2	449.7054	224.8527	365.93 **
Type of Binder (B)	1	20.6214	20.6214	33.56 **
AxB	2	7.8962	3.9481	6.43 **
Level of Binder (C)	2	89.3005	44.6503	72.66 **
AxC	4	27.3668	6.8417	11.13 **
BxC	2	3.7852	1.8926	3.08 ns
AxBxC	4	18.3139	4.5785	7.45 **
Error	36	22.1211	0.6145	
Total	53	639.1105		

** Highly significant at $\alpha=0.01$ R^2 (%) 96.54, CV 2.74

ns Not significant

Table 6 DMRT analysis on the effect of material, type of binder and level of binder on the VM of charcoal briquettes from Jatropha

Material	Type of binder	Level of Binder ^a			Average of Material	Ave. Type of Binder
		10	14	18		
100 % J. Husk	Cassava	29.16 de	28.49 e	34.57 a	30.83	Cassava
	Corn	30.27 cd	29.19 de	33.30 a		28.01
50 % Husk/50 % P. Cake	Cassava	28.13 ef	28.94 e	31.48 bc	29.85	Corn
	Corn	29.75 de	29.09 de	31.75 b		
100 % P. Cake	Cassava	23.61hi	23.15 i	24.55 gh	24.55	28.82
	Corn	23.34 hi	25.64 g	27.02 f		
Average Level of Binder		27.38	27.42	30.45		

^a Material x Type of Binder x Level of Binder; average of 3

Means marked with same letter in a column are not significantly different

level tends to increase the VM. Jatropha briquettes from pressed cake bound with either cassava or corn showed favorable results in terms of lower VM.

3.2.2 Ash content

Ash content in charcoal is the non-combustible residue left after charcoal is burnt. It represents the bulk mineral matter after carbon, oxygen, sulfur and water has been driven off during combustion. Jatropha husk shows the highest amount of ash content compared with

the combination of husk and pressed cake and the 100 % pressed cake (Fig. 6).

ANOVA of ash content of charcoal briquettes from Jatropha in Table 7 shows that the kind of material and level of binder significantly affect the ash content of Jatropha briquettes.

Further analysis using DMRT (Table 8) shows that type of material significantly affect the ash content of briquette. 100 % J. husk briquettes had significantly

Fig. 6 Ash content of Jatropha briquettes bound with cassava and corn starch at various binder level

Table 7 ANOVA on the ash content of charcoal briquettes from Jatropha

Source	DF	SS	MS	F-value
Material (A)	2	4793.1741	2396.5871	7879.89 **
Type of Binder (B)	1	0.1803	0.1803	0.59 ns
AxB	2	5.176	2.588	8.51 **
Level of Binder (C)	2	18.1651	9.0826	29.86 **
AxC	4	24.394	6.0985	20.05 **
BxC	2	1.448	0.724	2.38 ns
AxBxC	4	105.8942	26.4736	87.04 **
Error	36	10.9491	0.3141	
Total	53	4959.3808		

** Highly significant at $\alpha=0.01$

R² (%) 99.78, CV 1.98

ns Not significant

Table 8 DMRT analysis on the effect of material, type of binder and level of binder on the AC of charcoal briquettes from Jatropha

Material	Type of binder	Level of Bindera			Average of Material	Ave. Type of Binder
		10	14	18		
100 % J. Husk	Cassava	39.20 cd	38.47 d	41.74 b	40.22	Cassava 27.86
	Corn	45.00 a	39.43 c	37.45 e		
50 % J. Husk/ 50 % P. Cake	Cassava	28.24 f	26.93 g	24.47 h	26.48	Corn 28.19
	Corn	26.42 h	26.66 g	26.42 g		
100 % P. Cake	Cassava	18.23 i	17.42 ij	16.04 k	17.33	
	Corn	16.82 jk	18.09 i	17.39 ij		
Average Level of Binder		28.98	27.83	27.25		

aMaterial x Type of Binder x Level of Binder, average of 3

Means marked with same letter in a column are not significantly different

highest mean ash content compared to 100 % pressed cake and 50 % J. husk/50 % P. cake. This shows that J. husk contains higher non combustible residue after charcoal has been burnt. This was expected because Jatropha husk took longer time to carbonize. The type of binder did not significantly affect the ash content of the briquettes. Likewise, the average level of binder shows small difference, hence the variation of binder level and type of binder appears not significant. Good quality briquette typically has low amount of ash. Briquettes from pressed cake shows low ash content, hence a promising source of raw material.

3.2.3 Fixed carbon

The fixed carbon content of charcoal is the carbon found in the material which is left after volatile materials are driven off. This differs from the ultimate carbon content of the coal because some carbon is lost in hydrocarbons with the volatile. Fixed carbon is used as an estimate of the amount of coke that will be yielded from a sample of charcoal. Fixed carbon is determined by removing the mass of volatiles from the original mass of charcoal sample. The fixed carbon content is the most important constituent in metallurgy since it is the fixed carbon which is responsible for reducing the iron oxides of the iron ore to produce metal.

Fig. 7 shows the fixed carbon of Jatropha briquettes

bound with cassava and corn starch at different binder level. Jatropha briquettes from 100 % pressed cake bound with either cassava or corn had the highest fixed carbon content followed by 50 % J. husk/50 % P. cake and then 100 % J. husk. However, fixed carbon decreases when binder level increases.

Analysis of Variance of fixed carbon content of charcoal briquettes from Jatropha shows that the variation of material, type of binder and level of binder significantly affect the fixed carbon content of Jatropha briquettes as shown in Table 9.

A DMRT on the effect of material, type of binder and level of binder on the fixed carbon of Jatropha briquettes is shown in Table 10. The average of material shows that briquette from pressed cake is highest. Jatropha briquettes from 100 % pressed cake bound with cassava or corn at 10 % and 14 % level of binder did not significantly differ. It remains to be the highest compared with the other materials.

3.3 Crushing strength

The crushing strength is the maximum allowable load that the sample briquette can withstand. Fig. 8 shows the crushing strength of Jatropha briquettes bound with cassava and corn starch.

Fig. 7 Fixed carbon of Jatropha briquettes bound with cassava and corn starch at various binder levels

Table 9 ANOVA on the fixed carbon of charcoal briquettes from Jatropha

Source	DF	SS	MS	F-value
Material (A)	2	2475.6912	1237.8456	1199.95 **
Type of Binder (B)	1	25.2013	25.2013	24.43 **
AxB	2	8.6705	4.3352	4.20 *
Level of Binder (C)	2	42.2149	21.1075	20.46 **
AxC	4	33.1283	8.2821	8.03 **
BxC	2	10.1067	5.0533	4.90 *
AxBxC	4	39.165	9.7912	9.49 **
Error	36	37.1369	1.0316	
Total	53	2671.3148		

** Highly significant at $\alpha = 0.01$ * significant at $\alpha = 0.05$ R^2 (%) 98.61, CV 2.34

ns Not significant

Table 10 DMRT analysis on the effect of material, type of binder and level of binder on the FC of charcoal briquettes from Jatropha

Material	Type of binder	Level of Binder ^a			Average of Material	Ave. Type of Binder
		10	14	18		
100 % J. Husk	Cassava	37.19 ef	38.38 e	33.71 h	35.23	Cassava
	Corn	31.66 i	34.93 gh	35.53 fg		44.13
50 % J. Husk/ 50 % P. Cake	Cassava	43.64 c	44.13 c	44.05 c	43.3	Corn
	Corn	43.84 c	42.60 cd	41.82 d		
100 % P. Cake	Cassava	52.62 a	54.09 a	49.39 b	51.82	42.79
	Corn	52.91 a	52.59 a	49.31 b		
Average Level of Binder		43.64	44.45	42.3		

^a Material x Type of Binder x Level of Binder, average of 3

Means marked with same letter in a column are not significantly different

Materials bound with cassava starch showed a higher crushing strength compared to materials bound with corn starch as shown in Fig. 8. The 100 % pressed cake bound with 18 % cassava starch showed the highest strength at 53.25 kg/cm² followed by 100 % pressed cake bound with corn starch at 28.36 kg/cm². Lowest crushing strength was that of 100 % Jatropha husk bound with corn and cassava starch at 3.45 kg/cm² and 6.05 kg/cm² at 10 % level of binder, respectively. Results of the Analysis of

Variance (Table 11) for the crushing strength of charcoal briquettes from Jatropha show that material and type of binder significantly affect the crushing strength of Jatropha briquettes.

DMRT results revealed that materials bound with corn starch are much lower than materials bound with cassava starch (Table 12). Starch molecules have one of two molecular structures; a linear structure, known as amylose; and a branched structure known as amylopectin. The

Fig. 8 Crushing strength of Jatropha briquettes bound with cassava and corn starch at various binder levels

Table 11 ANOVA on the crushing strength of charcoal briquettes from Jatropha

Source	DF	SS	MS	F-value
Material (A)	2	4246.1068	2123.0534	77.71 **
Type of Binder (B)	1	1714.5615	1714.5615	62.76 **
AxB	2	350.1543	175.0772	6.41 **
Level of Binder (C)	2	1279.2193	639.6096	23.41 **
AxC	4	469.8578	117.4645	4.30 **
BxC	2	84.5381	42.2691	1.55 ns
AxBxC	4	52.443	13.1107	0.48 ns
Error	36	983.5267	27.3202	
Total	53	9180.4075		

** Highly significant ($\alpha = 0.01$)

R² (%) 89.29, CV 29.40

ns Not significant

Table 12 DMRT analysis on the effect of material and type of binder on the crushing strength of charcoal briquettes from Jatropha

Material	Type of Binder ^a		Average Material
	Cassava	Corn	
100 % J. Husk	10.24 c	4.46 d	7.35
50 % Husk/50 % P. Cake	21.95 b	11.97 c	16.96
100 % P. Cake	38.05 a	20.00 b	29.03
Average type of binder	23.41	12.14	

^a Material x Type of Binder x Level of Binder, average of 3

Means marked with same letter in a column are not significantly different

Table 13 DMRT analysis on the effect of material and level of binder on the crushing strength of charcoal briquettes from Jatropha

Material	Level of Binder ^a		
	10	14	18
100 % J. Husk	4.75 g	7.63 fg	9.68 efg
50 % Husk/50 % P. Cake	13.08 ef	15.72 de	22.09 a
100 % P. Cake	19.37 cd	26.91 b	40.80 a
Average level of binder	12.4	16.75	24.19

^a Material x Type of Binder x Level of Binder, average of 3

Means marked with same letter in a column are not significantly different

length of the amylose molecules in starch - known as its degree of polymerization - can vary tremendously. Cassava starch which has longer molecules tends to associate more strongly and produce stronger gels than corn starch which has shorter molecules.

Material and level of binder also have a significant effect on its crushing strength (Table 13). Jatropha briquettes bound with either cassava or corn starch at 10 % level of binder showed lowest crushing strength

than briquettes bound with 14 % and 18 % binder level. This indicates that the higher binder level, the higher the crushing strength. Briquettes from 100 % husk also shows lowest crushing strength than briquettes from 50 % husk + 50 % pressed cake and 100 % pressed cake. This is due to its lower bulk density of husk at 250 kg/cm³ as compared to the bulk density of cake at 355.1 kg/cm³. The lower the bulk density means greater surface area to be coated with binder, hence the more binder is required.

4. Conclusions

The average yield of *Jatropha* husk was higher than the pressed cake at 43.44 % and 38.76 %, respectively. Carbonization time of 5kg husk was 18 min compared to 10 min of pressed cake. Longer carbonization time of husk was influenced by the amount of volatile matter present in the material. Extra care was observed to prevent combustion of the material and inhibit the ashing of the product.

Jatropha briquettes from pressed cake bound with 18% cassava starch was found to have the highest crushing strength 53.25 kg/cm², while the next higher was that of pressed cake bound with 18% corn starch at 28.36 kg/cm². This shows that *Jatropha* briquettes from pressed cake bound with either cassava or corn starch is a good source of material in terms of crushing strength. 50 % husk and 50 % cake which is the second best, can also be a good source of material.

VM and AC of *Jatropha* briquette from pressed cake gave the lowest mean values of 24.55 % and 17.3 % respectively. VM and AC of 50 % husk and 50 % cake was higher 30.5 % and 26.21 %, respectively. FC of pressed cake showed highest mean at 51.82 % followed by the 50 % husk 50 % cake at 43.3 %. The higher the fixed carbon, the greater the amount of element available for combustion, hence, the greater the amount of heat released.

Gross heating value of pressed cake was highest at means of 20,782.97 J/g followed by 50 % husk + 50 % cake at 16,035.68 J/g, then husk at 11,277.09 J/g.

Although there is no existing Philippine National Standards for charcoal briquettes, *Jatropha* briquette from pressed cake and 50 % J. husk + 50 % P. cake can be considered as Grade B as per criteria set by PHILSA in

terms of heating values and crushing strengths.

Results of the study showed that a 10 % binder is ideal for briquettes from pressed cake and 50 % husk – 50 % cake. Any type of binder (cassava and corn starch) gives nearly the same properties with respect to VM, AC, FC and heating values. Likewise, it is recommended to use cassava starch as binder, because it produced stronger briquettes in terms of its crushing strength. The study only proved that *Jatropha* wastes can be a source of raw material for charcoal briquettes. However, in choosing the type of binder that will be used, economic aspects should be considered such as the cost of production and the availability of materials.

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