Development of corn cob-based fuel briquettes

Marc Gomerson A. Corpuz[1], Andres M. Tuates Jr.[2*], Teresito G. Aguinaldo[1], Elmar M. Villota[1], Wendy C. Mateo[1], Ofero A. Caparino[2]

(1. *Department of Agricultural Engineering, College of Engineering, Central Luzon State University, Science City of Muñoz, Nueva Ecija. Philippines*;

2. *Bioprocess Engineering Division, Philippine Center for Postharvest Development and Mechanization,CLSU Compound, Science City of Muñoz, 3120 Nueva Ecija. Philippines*)

Abstract: The study aimed to determine the optimum proportion of corn cob biomass material and binder for the production of fuel briquettes. Three levels of binding agent (10%, 15%, and 20%) and three particle sizes (<2.2 mm, 2.2-3.2 mm, and >3.2 mm) were applied in the experiments. The physical and thermal properties of the fuel briquettes were characterized in terms of density, shatter resistance, breaking strength, and burning time. Results showed that a mixture of 20% binding agent and <2.2 mm particle size of corn cob biomass material exhibited the best formulation with a bulk density of 0.30 g cm^{-3}, compression strength of 241.62 N, and shatter resistance of 99.25%. The potential energy density obtained for corn cob-based fuel briquettes was about 7890 MJ m^{-3}. Ten pieces of the produced briquettes can boil 500 mL of water in nearly 6 minutes. The mean burning time was 34 minutes and 16 seconds.

Keywords: corn cobs, fuel briquettes, physical properties, burning time

Citation: Corpuz, M. G. A., A. M. Tuates Jr., T. G. Aguinaldo, E. M. Villota, W. C. Mateo, and O. A. Caparino. 2017. Development of corn cob-based fuel briquettes. Agricultural Engineering International: CIGR Journal, 19(3): 92–96.

1 Introduction

Corn is the second to rice as the most important crop in the Philippines. In 2013, the Philippines produced 4,047,083 metric tons. Luzon contributed 3,068,990 metric tons, Visayas with 608,090 metric tons, and Mindanao with 370,003 metric tons (PSA, 2014).

Corn cobs are the agricultural waste products obtained from corn. After harvest, corn is processed for food, leaving a large quantity of corn cobs as waste on the farm with an estimated volume of 500-510 metric tons or equivalent to 13,150 GJ (Tuates, 2016). Aside from these, transportation and handling of corn cobs are also problems of corn farmers because of their low density. Zych (2008) claimed that corn cobs can be used for producing heat, power, gas or liquid fuels, and a wide variety of chemical products such as furfural, xylitol and activated carbon. Grover and Mishra (1996) reported that corn cob has low ash content (1.2%). Ash content of different types of biomass is an indicator of slagging behaviour of the biomass. Usually, slagging takes place with biomass fuels containing more than 4% ash and non-slagging fuels with ash content less than 4%. Utilization of these materials as source of alternative energy, particularly converting this into densified material or briquettes will add value to this waste product, and expected to contribute in lowering the fuel expenses by the intended users.

Briquettes made from corn cobs can be used as an alternative fuel to charcoal, firewood, or coal. Likewise, the handling of the product during transport and storage is easier because of its uniform size and shape and higher density (Tuates et al., 2013).

The establishment of the optimum proportion of the corn cob biomass and binder will pave a way for better utilization of briquettes in different operations and will maximize its benefits as biofuel. The study aimed to

Received date: 2016-10-21 **Accepted date:** 2017-07-24

*** Corresponding author: Andres M. Tuates Jr.,** Philippine Center for Postharvest Development and Mechanization, CLSU Compound Science City of Munoz, 3120 Nueva Ecija Philippines. Tel: 63444560213, Email: amtuates@yahoo.com.

determine the optimum proportion of the corn cob biomass and binder.

2 Materials and Methods

2.1 Collection and preparation of samples

Corn cobs were collected from the farm dumps at San Manuel, Isabela, and Philippines. The corn cobs were shredded using a shredding machine available at PHilMech. The shredded corn cobs were hammer milled to a desired particle size. The hammer milled biomass was sieved using standard sieves (3.2 and 2.2 mm mesh). The three particle sizes were >3.2 mm, 3.2–2.2 mm, and <2.2 mm.

2.2 Production of briquettes

Water and cassava starch were vigorously mixed and cooked until a desired consistency was achieved. The prepared binder was added to the hammer milled corn cobs and mixed using a mechanical mixer. Mixing of the materials was carried out for 5 min until the mixture become homogeneous and attained the uniform particle distribution and consistency. The produced mixture was unloaded from the mixer to a container and kept until it was ready for densification. The percent binding agent or the weight of cassava starch was computed based on the dried biomass by weight prior to mixing and briquetting operation.

2.2.1 Densification

The production of briquettes was conducted using piston-type briquetting machines. The biomass was punched into a die by a reciprocating ram with a very high pressure thereby compressing the mass to obtain a compacted product (Figure 1). 50 grams of the mixture were placed in each moulder of the briquetting machine. After placing the mixture, the cover of moulder was closed by manually tightening the nut. A power button of the electric motor was pressed to operate the hydraulic jack and compress the mixture inside of moulder. The densification process was stopped when the 5 cm length of briquette was achieved.

2.2.2 Drying

The densified briquettes were sundried until the moisture content reached less than 10% (wet basis) to avoid cracking as suggested by Grover and Mishra (1996). The moisture content was determined using the infrared moisture analyzer.

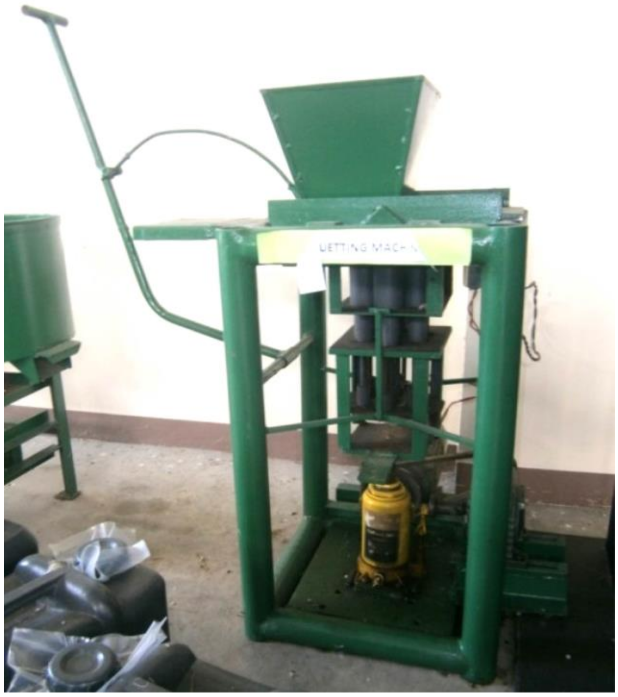

Figure 1 Briquetting machine

2.3 Determination of physical properties of briquettes

The physical properties of fuel briquettes produced were evaluated and analyzed in terms of density, shatter resistance and compression strength.

2.3.1 Density

Each corn cob fuel briquette sample was weighed and its dimension was measured after drying of fuel briquettes. The density in g cm^{-3} was calculated using the following Equation (1):

$$\text{Density} = \frac{M}{V} \tag{1}$$

where, M = Mass, g; V = Volume, cm^3.

2.3.2 Shatter resistance

The shatter resistance test was carried out to determine the property of the briquettes to resist impact during handling and transporting. Chendake (2012) suggested that three representative briquettes from the different treatments combinations will be dropped one-by-one one meter above the concrete floor. The shatter resistance of the briquettes was calculated using the following Equation (2):

$$\%\ \text{Weight loss} = \frac{(W_1 - W_2)}{W_1} \times 100 \tag{2}$$

$$\%\ \text{Shatter resistance} = 100\% - \%\ \text{Weight loss}$$

where: W_1 = Weight of briquette before shattering test; W_2 = Weight of briquette after shattering test.

2.3.3 Compressive strength

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 (INSTRON model). 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. A 5 kN load was applied at a cross head speed of 10 mm min^{-1} until the briquette failed by cracking or breaking.

2.3.4 Water boiling test

The water boiling test was performed following the procedures by Rathore (2008). A kettle was used in the test. The volume of kettle was measured and filled with 500 g water. The kettle was placed on top of a charcoal stove. 10 pieces of briquettes were weighed and used for the water boiling test. The initial temperature of the water at the kettle was measured and recorded. Final temperature of water after boiling was also measured. The water was heated until the briquettes were used up then the kettle cover was removed letting the water evaporated for 20 minutes. The kettle was removed from the stove. The temperature was lowered for 2 hours and the volume of water was measured.

2.4 Research design

The treatments were assigned following the two-factorial completely randomized design (CRD). Analysis of variance (ANOVA) table was utilized to determine the level of significance among the treatments. The differences among means were analyzed using the Duncan's multiple range test (DMRT).

Factor A = Binding agent

A_1 = 10%; A_2 = 15%; A_3 = 20%

Factor B = Particle size of corn cob biomass

B_1 = <2.2 mm; B_2 = 2.2-3.2 mm; B_3 = >3.2 mm

3 Results and discussion

3.1 Description of corn cob-based fuel briquettes

Figure 2 showed the corn cob-based fuel briquettes. The briquettes were cylindrical in shape with hole in the center to promote good combustion. The initial size of briquette was 50 mm in length with an outside and inside diameter of 50 and 16 mm, respectively.

a. >3.2 mm b. 2.2–3.2 mm c. <2.2 mm

Figure 2 Corn cob-based fuel briquettes using different particle sizes

3.2 Physical properties of corn cob briquettes

Tables 1, 2 and 3 showed the summary of the data gathered on the physical properties (i.e. density, shatter resistance and compressive strength) of the corn cob briquettes produced as affected by different amounts of binder and various particles sizes.

3.2.1 Density

The density of the corn cob briquettes as affected by the percent binder and different particle sizes was presented in Table 1. The highest density of fuel briquettes was obtained on the highest percentage of binder and lowest particle size of biomass with a mean value of 0.30 g cm^{-3}. This can be attributed to amount of binder and particle size. Chirchir (2013) stated that the strong bonds generated by gluing effected resulting in minimal expansion of briquettes after withdrawn from the mould. Likewise, the large particle sizes expanded greater than with smaller particles sizes resulting to greater volume and low density of the briquettes. Oladeji (2012) stated that the finer particle size had small pore spaces which were good for briquetting process.

Table 1 Density of corn cob-based fuel briquettes, g cm^{-3}

Binding agent	Particle size, mm			Average
	B1 (<2.2)	B2 (2.2-3.2)	B3 (>3.2)	
A1-10%	0.20	0.20	0.15	0.18^a
A2-15%	0.22	0.22	0.19	0.21^b
A3-20%	0.30	0.29	0.26	0.28^c
Average	0.24^a	0.24^a	0.20^b	0.22

Note: Means not sharing letter in common differ significantly by DMRT at 5% level of significance.

The analysis of variance revealed that there were significant differences in the different percentage of binder while the particle sizes of B1 (<2.2 mm) and B2 (2.2-3.2 mm) have significant differences in the particle size of B (>3.2 mm).

3.2.2 Shatter resistance

The percent shatter resistance of the corn cob-based fuel briquettes as affected by the percent binding agent and binder and different particle sizes was presented in Table 2. The low percent binding agent and larger particle size resulted to the lower percent shatter resistance of the briquettes. This can be associated to the amount of concentration of binder. The results were in agreement with the observation of Adenkule (2014), the shatter resistance increased with increase in amount of binder. Likewise, Adapa et al. (2003), Tabil and Sokhansanj (1996) classified the durability into high (>80%), medium (70%-80%) and low (<70%). The highest percent shatter resistance of 99.30% obtained from the produced fuel briquettes is classified as high durable.

Table 2 Shatter resistance of corn cob-based fuel briquettes, %

Binding agent	Particle size, mm			Average
	B1 (<2.2)	B2 (2.2-3.2)	B3 (>3.2)	
A1-10%	50.67	59.67	0.00	36.78^{a}
A2-15%	93.73	99.03	65.34	86.04^{b}
A3-20%	99.25	99.27	99.30	99.27^{c}
Average	81.22^{a}	85.99^{b}	54.88^{c}	

Note: Means not sharing letter in common differ significantly by DMRT at 5% level of significance.

The analysis of variance revealed that there were significant differences in the different percentages of binding and particle sizes.

3.2.3 Compressive strength

Table 3 showed the compressive strength of the corn cob-based fuel briquettes samples. The higher amount of binder and lower particle size of corn cobs resulted to higher breaking strength. Kaliyan et al. (2009) reported that binders with great viscosity like starch adhered to the surfaces of solid particles to generate strong bonds. Many viscous binders hardened after cooling and form solid bridges. Likewise, the finer the particle size also resulted to higher breaking strength of the briquettes. Grover and Mishra (1996) stated that great compressive strength and durability was expected to briquettes with high density.

Table 3 Breaking strength of corn cob-based fuel briquettes, N

Binding agent	Particle size, mm			Average
	B1 (<2.2)	B2 (2.2-3.2)	B3 (>3.2)	
A1-10%	3.16	14.59	0.00	5.92^{a}
A2-15%	39.92	29.09	17.1	28.70^{b}
A3-20%	241.62	93.61	83.67	139.63^{c}
Average	94.90^{a}	45.76^{b}	33.59^{b}	

Note: Means not sharing letter in common differ significantly by DMRT at 5% level of significance.

The analysis of variance revealed that there were significant differences in the different percentages of binding and particle sizes.

3.2.4 Optimum proportion of corn cob biomass and binder

The corn cob-based fuel briquette samples with 20% binding agent and <2.2 mm particle size exhibited a high density of 0.30 g cm^{-3}, the highest performance was in the compression test with a value of 241.62 N and good shatter resistance of 99.25%. Likewise, the burning time of the fuel briquettes samples is 34 minutes and 16 seconds, respectively. The mean ignition time was only 2 minutes and 5 seconds. It was also observed that the briquettes when ignited produced smoke but eventually vanished as the flame developed. This attribute of the briquettes made it more desirable for cooking. Ivanov et al. (2003) reported that smokeless fuels were known to contain no more than 20% volatile substances.

4 Conclusions

Based from the study, the optimum binding agent was 20% with a particle size of <2.2 mm. It exhibited a density of 0.30 g cm^{-3}, compression test of 241.62 N and shatter resistance of 99.25%.

The potential energy density of corn cob-based fuel briquettes was about 7,890 MJ m^{-3}. A 10 pieces of briquettes can boil 500 mL of water in nearly 6 minutes. The mean burning time of 10 pieces briquettes was 34 minutes and 16 seconds.

Acknowledgment

We would like to thank PHilMech and CEAT-UPLB for allowing the team to use their laboratory, equipment and instruments, and experimental area.

References

Adapa, P. K., G. J. Schoenau, L. G. Tabil, S. Sokhansanj, and B. Crerar. 2003. Pelleting of fractionated alfalfa products. *ASAE Annual Meeting*, Paper No. 036069. St. Joseph, Michigan: American Society of Agricultural and Biological Engineers.

Chirchir, D. K., J. M. Githeko, and D. M. Nyaanga. 2013. Effect of binder types and amount on physical and combustion characteristics. I*nternational Journal of Engineering Science and Technology*, 2: 12–20.

Department of agriculture. 2012. Geography of the Philippines. Available at http://da.gov.ph. Accessed April 4, 2012.

Grover, P. D., and S. K. Mishra. 1996. *Biomass Briquetting: Technology and Practices*. Bangkok, Thailand: Food and Agriculture Organization of the United Nations.

Ivanov, I. P., I. G. Sudakova, and B. Kuznetsovv. 2003. Manufacture of briquetted and granulated fuels from lignite with biobinders and heated die. *Chemistry for Sustainable Development*, 11(2003): 847–852.

Kaliyan, N., and R. V. Morey. 2009. Factors affecting strength and durability of densified biomass products. *Biomass and Bioenergy*, 33(3): 337–359.

Oladeji, J. T. 2012. Comparative study of briquetting of few selected agro-residues commonly found in Nigeria. *The Pacific Journal of Science and Technology*, 13(2): 80–86.

Philippine Statistics Authority (PSA). 2014. *Regional Agricultural Production Accounts*, 14th edition. Quezon City, Philippines: Philippine Statistics Authority.

Rathore, N. S. and N. L. Panwar. 2008. *Renewable Energy Theory and Practice*. New delhi, India: Himanshu Publication.

Tabil, L. G., and S. Sokhansanj. 1996. Process conditions affecting the physical quality of alfalfa pellets. *Applied Engineering in Agriculture*, 12(3): 345–350.

Tuates Jr, A. M. 2016. Bio-energy in the Philippines: status and utilization. Paper presented during the Bioenergy Information Day. Frankfurt, Germany.

Tuates Jr, A. M., A. R. Ligisan, and O. A. Caparino. 2013. *Utilization of Biomass Furnace By-products as Fuel Briquettes*. Saarbrücken, Germany: Lap Lambert Academic Publishing.

Zych, D. 2008. The viability of corn cobs as a bioenergy feedstock. West Central Research and Outreach Center, University of Minnesota.