

Techno-economic Evaluation of Fire Briquettes Using Different Waste Materials from Corn Plants

D.M.S.M. Dissanayaka¹, Udara S.P.R. Arachchige², Pabasari A. Koliyabandara¹, G.K.K. Ishara¹, A.R. Nihmiya¹, W.C. Nirmal²

¹Faculty of Technology, University of Sri Jayewardenepura, Sri Lanka

²Department of Mechatronic and Industrial Engineering, Faculty of Engineering, NSBM Green University, Sri Lanka
Email address: *udara.a@nsbm.ac.lk

Abstract—The abundance of agricultural waste has emerged as a concern in many nations primarily due to its large volume, necessitating effective management and utilization strategies. Researches are conducted to emphasize the utilization of biomass residues, often considered waste, to produce energy. Abundant and renewable biomass residues have the potential to alleviate environmental concerns. In this study, briquettes were manufactured using waste materials from corn plants, one of the most abundant agricultural wastes in Sri Lanka. The target was to analyze produced fire briquettes and verify their suitability for replacing biomass for combustion. The waste materials such as corn cob, corn husk, stalk and corn leaf were taken in the same portions as the raw material mixture. Initially, both proximate and ultimate analyses were conducted, followed by the completion of the drying curve. Subsequently, tests were performed on particles of four distinct sizes, namely 5 mm, 10 mm, 20 mm, and powder. The fixed carbon percentage values measured for the mentioned particle sizes were as follows, respectively: 8.63, 10.5, 8.9, and 7.56. The raw material of grounded corn waste and binding agent were varied to identify the optimum material mixing ratio for proper briquetting. Three parallel samples were produced for each ratio to minimize the manual and experimental errors.

Keywords—Air pollution control, biomass residues, briquettes, calorific value, life cycle assessment (LCA).

I. INTRODUCTION

Fossil fuel has been extensively utilized as a major energy source to meet global energy needs [1]. Coal, crude oil, and natural gas have rapidly increased to meet the increasing energy demands arising from global population growth, industrialization, and urbanization [2]. This surge in consumption is particularly notable as expanding populations seek improved living standards, industries grow, and urban areas expand rapidly. Coal, crude oil, and natural gas are pivotal in meeting these escalating energy needs, playing crucial roles in electricity generation, industrial processes, and various applications essential for modern life.

With the growing concern over the limited fossil fuel reserves and the effects of greenhouse gas emissions on Earth, there is considerable interest in alternative renewable energy sources for domestic and industrial applications [3]. Renewable energy sources like solar, biomass, wind, tidal, and geothermal are abundant in nature, with biomass being the third largest global energy source [4]. These renewable options are crucial in addressing energy demands while promoting environmental sustainability and offering clean alternatives to traditional fossil fuels [5]. Developed and developing countries have given biomass a vast consideration as a renewable energy source [6]. Biomass, including biomass residues, is a promising sustainable energy source, contributing to 14% of global energy consumption [7] due to its availability and renewability [8].

A significant downside of biomass energy is the competition between energy and food crops for cultivable land [9]. Improper biomass utilization can lead to deforestation through activities like clearing forests for energy crops and unsustainable logging. This problem can be resolved by utilizing biomass residues, which would otherwise go to waste, to produce energy. Biomass residues can also be called waste

materials. Biomass residues, including agricultural waste like husks, stalks, shells, and cobs, are increasingly used as renewable energy sources, ensuring affordability and security of energy supply [10, 11]. Agricultural residues can be utilized as a renewable energy source, either directly as solid fuel through combustion or through densification for domestic and industrial purposes [12]. However, due to their bulkiness, unevenness, high moisture content, and poor energy density, most agricultural wastes are not appropriate for direct use as fuel [12, 13]. These factors need to improve their practicality and efficiency in fuel applications.

So, a conversion process is needed to convert that residue into home and industrial energy through briquetting. Briquettes made from agricultural waste offer significant economic and environmental benefits as a viable alternative to fossil fuels [14]. Economically, the production and utilization of agricultural waste briquettes contribute to a more circular and resource-efficient economy. Transforming agricultural residues, such as husks, stalks, and shells, into a valuable energy source adds value to what would otherwise be considered waste and creates opportunities for local economic development. The cultivation, collection, and processing of agricultural waste for briquette production can generate employment and support local industries.

During the briquetting process, solid material particles are compressed to create blocks with specific shapes, sizes and ratios. These procedures enhance the biomass's handling properties while significantly increasing its energy content. This dual improvement in handling and energy content underscores the efficacy of briquette in optimizing biomass for practical use and sustainable energy production.

In this study, briquettes will be manufactured using waste materials from corn plants, which are most abundant in Sri Lanka. This represents a significant advancement in converting

these waste materials into a tangible energy source suitable for domestic and industrial use. This research aims to analyse this fire briquette and verify its suitability for replacing biomass.

II. MATERIALS AND METHODS

Materials

The materials used for this research are Corn plants' waste as raw materials and waste starch (wheat flour) as a binding agent. The corn waste was taken from the Bibile (village of Uva province) area of Sri Lanka. It is one of the most abundant cultivations. So, a lot of corn waste remains after harvesting the corn. The binding agent (starch-wheat flour) was purchased from the market cheaply because expired flour that was not eligible for use was purchased.

Method - Sample preparation

After harvesting the corn, sundried them. After sun drying the corn stoves, they were ground using a grinder machine to transform them into powder form.

The corn stover powder was mixed with measured quantities of starch (wheat flour). First, the required quantity of starch was measured and thoroughly mixed with water at a specific ratio of 50 mL for 10 g of starch. Then, the measured corn stover and made pulp of starch was mixed thoroughly together. Then, the mixture was filled into the moulds in the briquette machine. The mould dimensions of mould are 8cm*8cm*8cm. After filling the mixture in the moulds, the mixture was compacted until the height of the briquettes was 4 cm using a screw in the machine. So, the compact ratio is 1:0.5. The two parallel samples of briquettes were made to each ratio to 1:1 (binder to corn stover powder) ratio to 1:7. The whole sample weight was 120 g (Binder + Corn stover powder) per each briquette. First, the mixture was made with starch and powder from a corn stover, then filled into a machine and ejected after compacting the briquettes. The compact ratio is 1 to 0.5. After ejecting the briquettes, they were kept for sun drying in average conditions to reduce the moisture content in them. Fig. 1 shows the manufactured briquettes using this method.



Fig. 1. Manufactured briquettes

III. EXPERIMENTAL DETAILS

Proximate analysis of raw materials

The proximate analysis includes four tests. They are moisture content, volatile matter, ash content and fixed carbon content.

1) Moisture content

The moisture contents of samples were measured by keeping samples at 105 Celsius for 3 hours in the muffle furnace [15]. The moisture content was calculated according to equation 1.

$$\text{Moisture content} = \frac{\text{Initial weight} - \text{Final weight}}{\text{Initial weight}} \times 100 \% \quad (1)$$

2) Volatile matter content

The Volatile matter content of samples were measured by keeping dried samples (105 Celsius for 3 hours) at 950 Celsius for 7 minutes in the muffle furnace [16]. The volatile matter content was calculated according to equation 2.

$$\text{Volatile Matter content} = \frac{\text{Initial weight} - \text{Final weight}}{\text{Initial weight}} \times 100\% \quad (2)$$

3) Ash content

The ash content of samples were measured by Keeping dried base samples at 750 Celsius for 3 hours in the muffle furnace. The ash content was calculated according to equation 3.

$$\text{Ash Content} = \frac{\text{Final weight after ignition}}{\text{Initial weight of the sample}} \times 100\% \quad (3)$$

4) Fixed carbon content

The fixed carbon content was calculated by subtracting the volatile matter content and ash content from 100%. The ash content was calculated according to equation 4.

$$\text{Fixed Carbon content} = 100 - (\text{Volatile matter} + \text{Ash content}) \% \quad (4)$$

Ultimate Analysis for raw materials

According to the proximate analysis results Ultimate analysis was done. The quantity of Carbon, Oxygen and Hydrogen were calculated here. The Carbon content of raw materials was calculated according to equation 5.

$$C = 6.637 * \text{Fixed carbon \%} + 0.455 * \text{Volatile Matter \%} \quad (5)$$

The Hydrogen content of raw materials was calculated according to equation 6.

$$H = 0.052 * \text{Fixed carbon \%} + 0.062 * \text{Volatile Matter \%} \quad (6)$$

The Oxygen content of raw materials was calculated according to equation 7.

$$O = 0.304 * \text{Fixed carbon \%} + 0.476 * \text{Volatile matter \%} \quad (7)$$

Thermogravimetric analysis (TGA) of the raw Corn stover

The TGA test was done to find the thermal decomposition behaviours of corn stover. The multiple weight loss stages in the TGA curve can indicate the breakdown of different components in the corn stover, such as cellulose, hemicellulose, and lignin. This information helps to understand the overall composition of feedstock and predict its combustion characteristics.

Briquettes testings – Density

The density of briquettes was determined by measuring the mass and the volume of the briquettes and using equation 8.

$$\text{Density (g/cm}^3\text{)} = \text{Mass of briquette (g)}/\text{Volume of briquette (cm}^3\text{)} \quad (8)$$

Ignition time

The average time required to ignite a briquette is the ignition time of the briquette [17]. The ignition time of the manufactured briquettes was assessed alongside the burning rate test. A 50g portion of the briquette sample was positioned on a stand and lit using a candle. The stopwatch commenced once the candle was lit and continued until the briquette caught fire. The time taken for ignition was then noted.

Burning rate

The burning speed of the manufactured briquettes was gauged by employing a custom-made insulated stand. The burning rate of the briquettes was assessed by measuring their weight both before and after complete combustion [18]. A 50g portion of the briquette sample was positioned on the stand and set alight. Timing commenced as soon as the sample ignited. Following the complete combustion of the briquette sample, the weight of the residue was determined. Equation 9 was then used to compute the weight reduction at a particular interval.

$$\text{Burning rate (g/min)} = (W_1 - W_2)/T \quad (9)$$

Where, W_1 = Initial weight of briquette sample (g)

W_2 = Final weight of fuel after burning (g)

T = Total burning time (min)

IV. RESULTS AND DISCUSSION

Proximate analysis of raw materials

Here, proximate analysis was done on the corn plant (corn stover) waste at four different sizes of particles. They are 5mm, 10mm, 20mm and powder. Three parallel samples were tested. Table 1 represents the average moisture content, average volatile matter content, average ash content and the average fixed carbon content for the above four sizes of particles.

TABLE 1. proximate analysis results for different particle sizes of samples

Particle size	Avg. moisture	Avg. volatile matter	Avg. ash content	Fixed carbon
5mm	8.76	89.22	2.15	8.63
10mm	10.74	87.85	1.66	10.5
20mm	8.48	89.47	1.64	8.9
Powder	7.96	89.70	2.74	7.56

Ultimate Analysis for raw materials

Below Table 2 represents the ultimate analysis results for the raw material.

TABLE 2. The ultimate analysis results for the raw material

Particle size	Avg. moisture	Avg. volatile matter	Avg. ash content	Fixed carbon	C	H	O
5 mm	8.76	89.22	2.15	8.63	46.09	5.98	5.95
10 mm	10.74	87.85	1.66	10.5	46.66	5.99	45.01
20 mm	8.48	89.47	1.64	8.9	46.38	6.01	45.29
Powder	7.96	89.70	2.74	7.56	45.63	5.95	45.29

Thermogravimetric analysis (TGA) of the raw Corn stover

Initially, a thermal occurrence, spanning approximately 25 to 125 °C, corresponds to the loss of moisture from the fibre. Despite prior drying, the fibre's hydrophilic nature causes it to reabsorb moisture. Corn stover exhibits thermal stability until

roughly 210 °C, after which the breakdown of hemicellulose commences, occurring between approximately 245 and 350 °C. The third event, transpiring around 355 °C, is associated with the decomposition of volatile cellulose components. Fig. 2 below represents the TGA testing result curve.

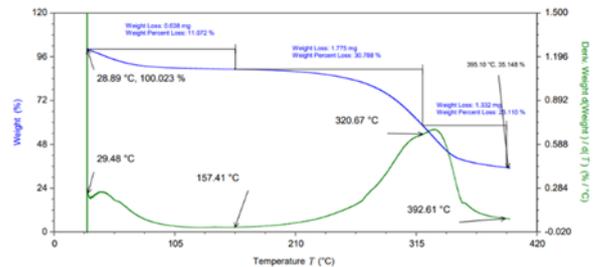


Fig. 2. TGA testing result curve

The examination of the decay curve for corn waste (depicted in Figure 2) reveals three distinct instances of mass reduction. Stage I started at around 28 °C and finished at 158 °C. The stage corresponded to the release of moisture and the light volatile compound, characterized by the appearance of the first basin on the TG curve. In this study, the decreasing sample mass was about 11.072 %, while the proximate test result showed that the water content was around 7 - 11% in four different sizes of raw material samples. Stage II occurred in the temperature range around 158-321 °C. This stage was also called the active pyrolysis stage, a significant degradation stage of the organic component, in which most of the mass was decomposed and released to become volatile [20]. The appearance of a sharp slope on the TG curve indicated this phenomenon. 30.788% of the corn sample mass was decomposed at this stage. Stage III was presented in the temperature range of around 321-396 °C. It indicated that carbon in biochar was continuously decomposed. A total of 23.112% decrease in this stage. After that, carbon components and thermal decomposition of inorganic components from corn waste are further decomposed.

Briquettes testings' results - Densities of briquettes

The results for density that resulted corn stover: starch briquettes are shown in Fig. 3.

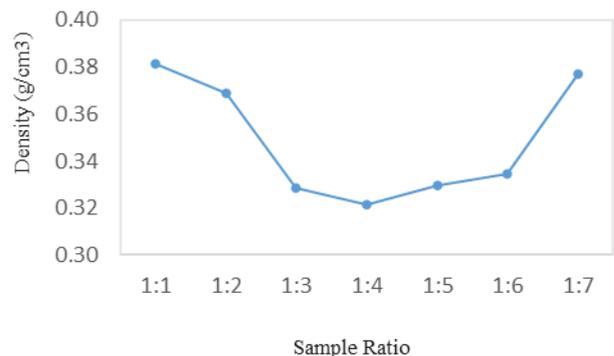


Fig. 3. Densities of the briquettes

In some samples were obtained significant relationships that density with a high proportion of binding agent shows a higher density.

The result of the average density calculation of the briquettes in Fig. 3 shows that samples with higher starch content have the significantly highest density among other ratios of briquettes apart from the 1:7 ratio of briquette, the higher the levels of starch, the higher the density of briquettes. This happens because the briquette pores will decrease due to the binding holding capacity increasing highly [20]. Also, binding holding capacity increases when particle size is reduced [21].

Ignition time

The ignition time for the briquette samples 1:1, 1:2, 1:3, 1:4, 1:5, 1:6 and 1:7 was 5.13 min, 4.25 min, 4.39 min, 3.95 min, 2.52 min, 2.54 min and 2.50 min. The comparison of ignition time in minutes for all the samples is presented in Fig. 4.

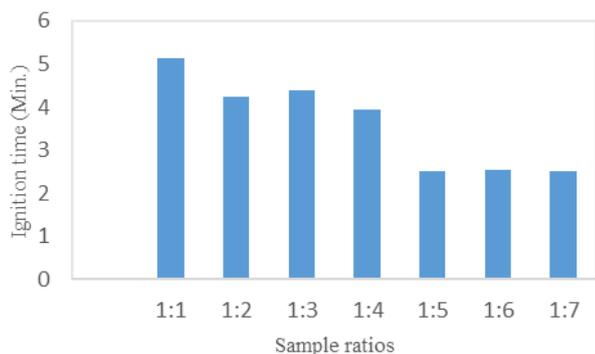


Fig. 4. Ignition time for the briquette's samples

The ignition time for briquettes with a high quantity of binding agent is significantly higher. The 1:1 ratio of briquette has the highest ignition time for burning. The ignition duration rises as density increases, and density elevates with the type and quantity of binder, leading to stronger bonding [22]. The lowest burning time you had was the briquette of 1:7 ratio. Ignition time holds considerable importance in briquette applications, as a shorter ignition time enhances the briquette's quality.

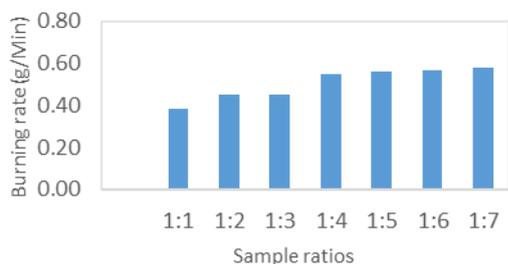


Fig. 5. The burning rates

Burning rate

The burning rate typically slows as the binder content increases in biomass briquettes. This phenomenon occurs because the increased binder content enhances the cohesion and compactness of the briquette, making it denser and more resistant to rapid combustion. Consequently, while a higher binder content can improve the structural integrity of the briquette, it may also lead to a decrease in the burning rate. The burning rates for all briquette samples are shown in Fig. 5.

The briquette with a ratio of 1:7 exhibited the highest burning rate due to its lower quantity of binding agent than the other briquettes. In contrast, the briquettes with a ratio of 1:1 showed the lowest burning rate because of their higher binding agent content than the other briquettes.

V. CONCLUSION

Corn stover biomass briquettes were found to be a good source for altering conventional biomass because they have good combustion properties and physical properties after being identified with the binding agent of wheat flour. The briquette with a ratio of 1:7 demonstrated the lowest burning time and the fastest burning rate because it contained a lower amount of binding agent compared to the other briquettes. Ignition time holds considerable importance in briquette applications, as a shorter ignition time enhances the briquette's quality. Furthermore, it's essential to assess the calorific value to determine the ideal briquette for comparison with biomass, ensuring the efficacy of the substitution. Conducting a Life Cycle Assessment of the briquette is necessary to confirm the carbon footprint associated with its production in this study.

REFERENCES

- [1] Olorunsola, A. (2007). Production of fuel briquettes from waste paper and coconut husk admixture (Vol. 9). *Agricultural Engineering International: The CIGR E-Journal*, Manuscript EE 06 006.
- [2] Obi, F. O., & Okongwu, A. C. (2016). Characterisation of fuel briquettes made from a blend of rice husk and palm oil mill sludge. *Biomass Conversion and Biorefinery*, 6(1), 449–456.
- [3] Ajimotokan, H. A., & Sher, I. (2015). Thermodynamic performance simulation and design optimisation of trilateral-cycle engines for waste heat recovery-to-power generation. *Applied Energy*, 154, 26–34.
- [4] Javed, M. S., Raza, R., Hassan, I., Saeed, R., Shaheen, N., Iqbal, J., & Shaukat, S. F. (2016). *Journal of Renewable and Sustainable Energy*, 8, 043102.
- [5] FAO. (2010). Banana production by countries 2010. Retrieved from <http://faostat.fao.org/site/339/default.aspx>
- [6] Grover, P. D., & Mishra, S. K. (1996). *Biomass Briquetting: Technology and Practice*. Food and Agriculture Organization of the United Nations, Bangkok, Thailand, 1–10.
- [7] Rabi, A. B., Lasode, O. A., Ajimotokan, H. A., & Afolayan, V. A. (2018). Combustion characteristics of selected tropical wood residues in relation to particle size. *Proceedings of the 33rd International Conference on Solid Waste Technology and Management*, 320–330, PA, USA.
- [8] Saponpongpiat, N., & Sae-Ueng, U. (2015). The effect of biomass bulk arrangements on the decomposition pathway in the torrefaction process. *Renewable Energy*, 81, 679–684.
- [9] Sims, R. E. H., Mabee, W., Saddler, J. N., & Taylor, M. (2010). An overview of second-generation biofuel technologies. *Bioresource Technology*, 101, 1570–1580. <https://doi.org/10.1016/j.biortech.2009.11.046>
- [10] Eddine, B. T., & Salah, M. M. (2012). Solid waste as renewable source of energy: Current and future possibility in Algeria. *International Journal of Energy and Environmental Engineering*, 3, 1–12.
- [11] Szyszlak-Bargłowicz, J., Zajac, G., & Piekarski, W. (2012). Energy biomass characteristics of chosen plants. *International Journal of Agrophysics*, 26(2), 175–179.
- [12] Ibitoye, S. E. (2018). *Production and characterisation of fuel briquettes made from blend of corncob and rice husk*. M.Eng Project Report, University of Ilorin, Department of Mechanical Engineering, Nigeria.
- [13] Wilaipon, P. (2007). Physical characteristics of maize-cob briquettes under moderate die pressure. *American Journal of Applied Sciences*, 4(5), 995–998.
- [14] Yamaji, F. M., Chrisostomo, W., Vendrasco, L., & Flores, W. P. (2010). The use of forest residues for pellets and briquettes production in Brazil. *Proceedings of the Venice Conference*.

- [15] Ivanova, T., Muntean, A., & Havrand, B. (2012). Drying of cherry tree chips in the experimental biomass dryer with solar collector. *Research in Agricultural Engineering*, 58(1), 16–23. <https://doi.org/10.17221/10/2011-RAE>
- [16] Kongprasert, N., Wangphanich, P., & Jutilaprtavorn, A. (2019). Charcoal briquettes from Madan wood waste as an alternative energy in Thailand. *Procedia Manufacturing*, 30, 128–135. <https://doi.org/10.1016/j.promfg.2019.02.019>
- [17] Nyaanga, D. M., Kabok, P. A., Mbuba, J., Abich, S. O., Eppinga, R., & Irungu, J. (2018). Faecal matter–saw dust composite briquette and pellet fuels: Production and characteristics. *41st WEDC International Conference*, Egerton University, Nakuru, Kenya, 1–7.
- [18] Onuegbu, T. U., Ekpunobi, U. E., Ogbu, I. M., Ekeoma, M. O., & Obumselu, F. O. (2011). Comparative studies of ignition time and water boiling test of coal and biomass briquettes blend. *International Journal of Recent Research and Applied Studies (IJRRAS)*, 7(2), 153–159.
- [19] Bach, Q. V., & Chen, W. H. (2017). Pyrolysis characteristics and kinetics of microalgae via thermogravimetric analysis: A state-of-the-art review. *Bioresource Technology*, 246, 88–100. <https://doi.org/10.1016/j.biortech.2017.06.087>
- [20] Orisaleye, J. I., Jekayinfa, S. O., Adebayo, A. O., Ahmed, N. A., & Pecenka, R. (2018). Effect of densification variables on density of corn cob briquettes produced using a uniaxial compaction biomass briquetting press. *Energy Sources, Part A: Recovery, Utilization and Environmental Effects*, 40(24), 3019–3028. <https://doi.org/10.1080/15567036.2018.1516007>
- [21] Arachchige, U. S. P. R. (2021). Briquettes production as an alternative fuel. *Nature Environment and Pollution Technology*, 20(4), 1661–1668. <https://doi.org/10.46488/NEPT.2021.v20i04.029>
- [22] Kaur, A., Roy, M., & Krishnend, K. (2017). Densification of biomass by briquetting: A review. *International Journal of Recent Scientific Research*, 10, 20561–20568. <https://doi.org/10.24327/IJRSR>