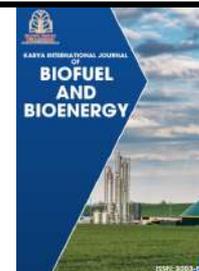




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Banana Pseudostem Waste Bio-Briquettes using Cassava Peels Binder

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ABSTRACT

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This research explores the potential of banana pseudo-stem waste and cassava peels (binder)—both abundant agricultural wastes in Uganda for the production of bio-briquettes as a sustainable energy source. While banana pseudo-stems account for 60% of banana waste, mechanical fiber extraction generates a large amount of trash that is largely discarded. Cassava peels, on the other hand, offer a starch-rich, non-edible alternative to traditional food-based binders like cassava starch. The study involves converting Banana plant pseudo-stem waste into biochar, then into briquette feedstock, and using cassava peel starch as a binder at varying ratios. Bio-briquette samples were produced using different compaction loads, and their physical, Mechanical and thermal properties were tested to validate performance. The conducted tests resulted in a calorific value of 8.172 MJ/Kg, a burning rate of 6.85g/min, a heat utilization efficiency of 91%, a moisture content of 8.8%, a compressive strength of 0.83 MPa, and an average density of 232kg/m³. The project aims to reduce agricultural waste, provide clean energy, enhance food security, and support circular economy practices in Sub-Saharan Africa.

1. Introduction

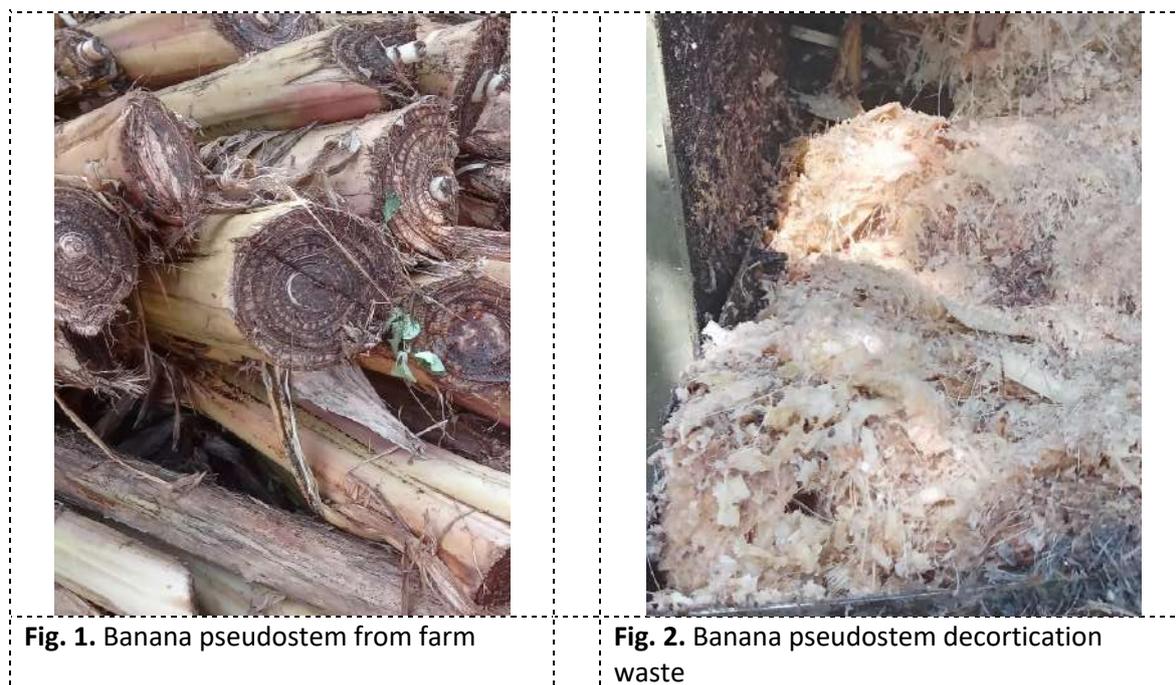
1.1 Background

Bio-briquettes are energy sources for cooking and other heating needs made of organic materials [1]. Formation involves densification of biomass to facilitate better handling, easier transportation, and an increase in calorific value by volume, production of uniform, clean, and stable fuel[2]. Process variables most important in briquette production include initial moisture content, granulometry, pressure, compaction time, and binder [3]. The increasing global population, now at 20% annually, is expected to reach 9 billion by 2050, thereby increasing agricultural product consumption and agricultural waste. Failure to sustainably re-use these wastes gives room to decomposition, which generates methane, hydrogen sulphide, and ammonia, which are greenhouse gases [4-7]. Consequently, the majority of agricultural wastes are rich in cellulose, hemicellulose, and lignin, which, when burnt, produce black carbon, a major source of air pollution [8].

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Banana is a staple food and a continuous source of income to farmers in most parts of Uganda throughout the year [9]. Also cultivated in Rwanda and the western part of Tanzania, the East African highland bananas (AAA-EA) have extremely high productivity [10]. But for every tonne of harvested bananas, 4 tonnes of waste are obtained, which include leaves, pseudo-stem, peels, rhizomes, empty fruit bunches, and rejected fruits [11]. Efforts to valorise these wastes are being enhanced in sub-Saharan Africa into bio-fertilizers, bio-fuel, and other value-added products [12,13]. Figure 1 shows a heap of banana pseudostem delivered after banana fruit harvest. When these underwent mechanical fibre extraction through a decortication machine in TEXFAD Ltd, Kampala, Uganda the trash shown in figure 2 was obtained with no tangible economic use. According to TEXFAD Ltd, 85% of trash consisting of both solid and liquid waste is generated from single pseudostem decortication in mechanical fibre extraction.



Consequently, cassava is grown and consumed (37%) in the eastern region, (34%) Northern region, (15%) western region, and (14%) in the central region of Uganda. Cassava starch, being a staple food, is not recommended as a binder [6].

There is no evidence so far of any attempt to use solid waste from mechanical decortication of banana pseudostem as a sole feedstock for briquette production. In addition, this research has employed use of cassava peels as binder which is also a waste from cassava tuber. The significance of this research is to reduce global warming, enhance environmental conservation, increase jobs in banana growing areas and improve the economic value from banana crop. The main objective was to produce and determine properties of bio-briquettes from 100% banana pseudostem waste feedstock and cassava peels binder, an environmentally friendly fuel.

1.2 Literature Review

The suitability of banana waste as a feedstock for biochar has been proven, as it contains high levels of cellulose and lignin. Furthermore, it contains high organic carbon material and is highly resistant to decomposition. Its ability to remove heavy metals and other contaminants from wastewater by adsorption is a major factor enhancing its prominence [14]. It is recommended that

proximate analysis on briquette feedstock is done before production to ascertain the required properties. Sulphur and nitrogen should be minimal to ensure the least amount of environmental pollution [15]. Consequently, the combustion efficiency of a fuel is determined by its carbon content [16].

Lomunyak *et al.*, [17] used acacia charcoal dust with starch, paper, and algae as binders at 10%, 15%, 20%, 25% and 30% of the total weight of individual samples. The charcoal-starch sample briquette with 30% starch binder proportion gave the best calorific value, ignition time, and burning rate [17]. According to ISO 16559, biomass is any material of biological origin, excluding those embedded in geological formations undergoing mineralization. Plant origin biomass is lignocellulosic in nature, rich in energy content, as it contains lignin, cellulose, hemicellulose, and a few organic components like lipids and extractives [18].

Pyrolysis is the thermal decomposition of organic matter in the absence of oxygen, resulting in biochar, oil, and gas [19]. Biochar is a black carbon-rich and porous solid material (similar to charcoal) that can be produced through thermochemical conversion of biomass in the presence of little oxygen or no oxygen [20]. Ngene *et al.*, [21] in a review on biochar briquetting, concluded that mechanical and environmental performances determine the fulfilment of biochar briquette applications. On the same note, an increase in binder load increases mechanical strength but could lead to a decrease in calorific value, an increase in emissions, and ash content [21].

The effectiveness of briquetting depends on the type and properties of the binder used. Binders should have a strong bond, be economically available, pollution-free, and should not interfere with the heat release and combustibility of the briquette. They determine strength, thermal stability, cost of briquette, and combustion performance [22,23]. Narzary *et al.*, [24] compared starch binder, paper binder, and taro in the production of rice straw briquettes. The starch was of lab grade, where 10grams was added to 50ml of water and heated to the boiling point until it gelatinized before use. It was concluded that starch binders at a 20% ratio produced briquettes with the best thermal stability. However, starch, being a source of human food, makes it unsuitable as a commercial binder [24].

Starch extracted from cassava peels was observed in a Fourier Infra-Red Spectrometer and compared with starch from cassava tuber on the same equipment. The two samples presented similarity in the active groups, suggesting that the two starch samples have similar binding ability [25]. Biomass is heterogeneous in terms of shape, size, and composition, characterized by low bulk density, leading to difficulties in transport, handling, and storage. Okot et al established that low pressures (5-31) MPa used to compact maize residues produced less than 1000kgm⁻³ briquette density, which is less than the German standard DIN 51731 requirements of (1000-1400) kgm⁻³ [26].

1.2.1 Moisture content

Dyjakon *et al.*, [27] determined the moisture content before the pressure agglomeration process according to PN-EN ISO 18134-2: 2017-03E standard at 105 °C for 24 hours. [27].

$$MC = \frac{m_b - m_c}{m_b - m_a} \times 100\% \quad 1$$

Where: MC - moisture content of sample (%), m_a - mass of the empty crucible, m_b - mass of the crucible with sample in the analytical state (g), m_c - mass of crucible with sample after drying (g)

1.2.2 Volatile matter

To determine the volatile matter, remaining samples from the moisture content test were heated in a furnace at 950 °C for 7 minutes according to ASTM D3175 [28].

$$VM = \frac{w_3 - w_4}{w_3 - w_1} \times 100\% \quad 2$$

Where: VM – volatile matter, w_1 – weight of empty crucible (g), w_3 – weight of empty crucible + remaining sample taken from moisture content examination (g), w_4 – weight of empty crucible + sample after cooling (g).

1.2.3 Ash content

$$\text{Ash Content} = \frac{w_5 - w_1}{w_4 - w_1} \times 100\% \quad 3$$

Where: w_1 – weight of empty crucible (g), w_4 – weight of empty crucible + remaining sample taken from volatile matter examination (g), w_5 – weight of empty crucible + ash left in the crucible (g).

1.2.4 Fixed carbon

Fixed carbon is determined by subtracting moisture content, volatile matter, and ash content from the original mass of the sample according to ASTM D3172 [28].

$$\text{Fixed carbon (\%)} = 100(\%) - \text{MC (\%)} - \text{VM (\%)} - \text{AC (\%)} \quad 4$$

1.2.5 Calorific value

The calorific value of the samples is determined using a bomb calorimeter according to ASTM D5865 [28, 29]

$$Q = \frac{(C_{\text{water}} - C_{\text{cal}})(T_2 - T_1)}{W_f} \quad 5$$

Where: Q – calorific value (KJ/Kg), C_{cal} – Heat capacity of the bomb calorimeter (KJ/Kg °C), C_{water} – Heat capacity of water (KJ/kg °C), W_f – mass of sample (Kg), $T_2 - T_1$ – Temperature rise (°C).

1.2.6 Bulk density

Bulk density is given by mass divided by volume [28]

$$\rho = m/v \quad 6$$

where ρ – bulk density (g/cm³), m – mass of charcoal briquette (g), v – volume of charcoal briquette (cm³).

1.2.7 Burning rate

Burning rate is the rate at which a certain mass of charcoal briquette is combusted in air [28].

$$\text{Burning rate} = \frac{m_b}{t} \quad 7$$

Where; m_b – mass of charcoal briquettes burnt (g), t – total burning time (minutes)

1.2.8 Heat utilization efficiency

Heat utilization efficiency is determined using the standard water boiling test [28].

$$HU (\%) = \frac{M_w C_p (T_b - T_o) + M_c L}{M_f H_f} \times 100 \quad 8$$

Where; M_w – mass of water (kg), C_p – specific heat capacity of water (KJ/Kg °C), T_b – boiling temperature (°C), T_o – initial temperature of water (°C), M_c – mass of water evaporated (kg), L – latent heat of vaporization (KCal/kg), M_f – mass of charcoal briquette burnt (kg), H_f – calorific value of charcoal briquettes (KJ/kg)[28].

Sawekwiharee *et al.*, [30] obtained a heat utilization efficiency of 18.01% and a burning rate of 11.90g/min from cashew nut shell briquettes. The research concluded that cashew nut shells briquettes cannot replace firewood nor reduce cost for heating manufacturing processes [30]. A burning rate of 9.7g/min and a density of 560 kg/m³ were obtained by Nurba *et al.*, [31] on Corncobs briquettes whereas wood charcoal briquettes yielded 9.8g/min burning rate and 1160 kg/m³ density [31].

2. Methodology

2.1 Material Processing

2.1.1 Pseudostem waste processing

Pseudostem waste was obtained from TEXFAD Ltd in Kampala, Uganda. The waste was carried in two twenty-litre jerricans to Busitema University, where excess water was squeezed out. Total volume drop by squeezing was 20%. The waste was then sun-dried within the university for three days of eight hours per day. These materials were then dried to 15% moisture content in the laboratory conditioning chamber at the materials lab in Busitema University. Long waste pieces were trimmed to 10mm in length. At this point, waste in powder form was already approximately 10% of the total. A total of 20 litres of dry pseudo-stem waste was obtained from the 40 litres collected from the source. Figure 3 shows the main pseudo-stem waste packaging for transport from TEXFAD Ltd to Busitema university. The trash was then sundried in the open naturally as shown in figure 4.



Fig. 3. Banana pseudostem waste packed for transportation



Fig. 4. Sun-drying banana pseudostem waste

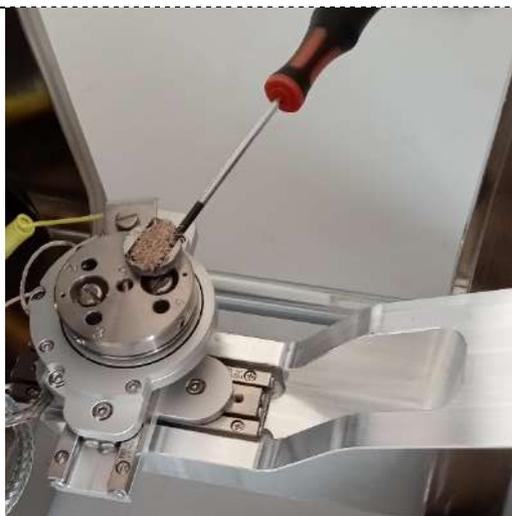


Fig. 6. Scanning electron microscope sample mounting



Fig. 7. Fourier transform infrared spectrometer setup

Morphological images obtained from a magnification of $50\mu\text{m}$ and $100\mu\text{m}$ under scanning electron microscope are shown in figure 8 and 9. The images show an irregularly rough surface which is an indication of enlarged surface area. It is important to note that the enlarged surface area is essential for binding effectiveness of the material. The larger the surface area, the better the binding action. In addition, the fibre has no specific orientation or arrangement in the mass. This adds up in the overall strength properties of briquettes due to intertwining nature of the fibre.

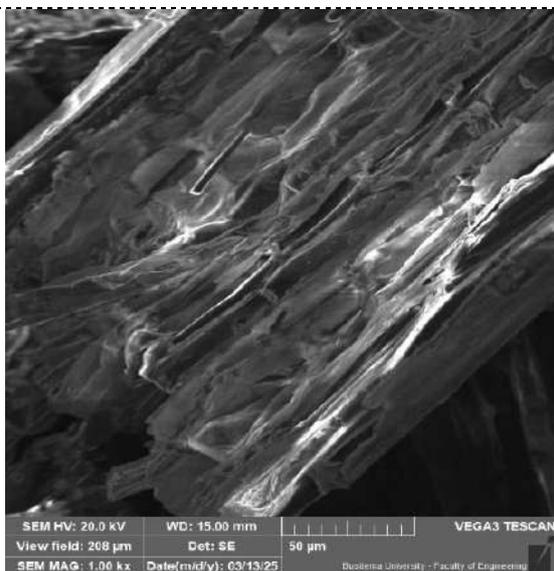


Fig. 8. Waste fibre micrograph under $50\mu\text{m}$

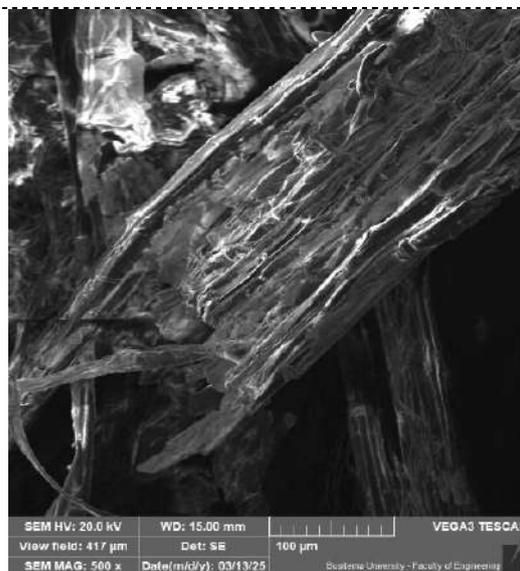


Fig. 9. Waste fibre micrograph under $100\mu\text{m}$

Powder from dried pseudostem waste was also put under focus to determine its morphological structure and its likely influence on the final characteristics of the briquette. It is noted that the powder material interlinks between the fibres and contributes to the mechanical strength of bio-briquettes formed. The morphological images under a magnification of $50\mu\text{m}$ and $500\mu\text{m}$ in a scanning electron microscope were seen as indicated in figure 10 and 11. Despite the small size of the particles, they also have a rough surface necessary for binder anchoring and effectiveness.

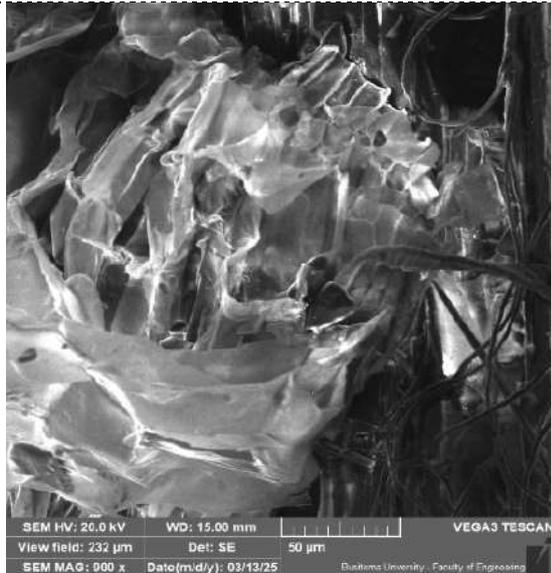


Fig. 10. Waste powder micrograph under 50µm using SEM

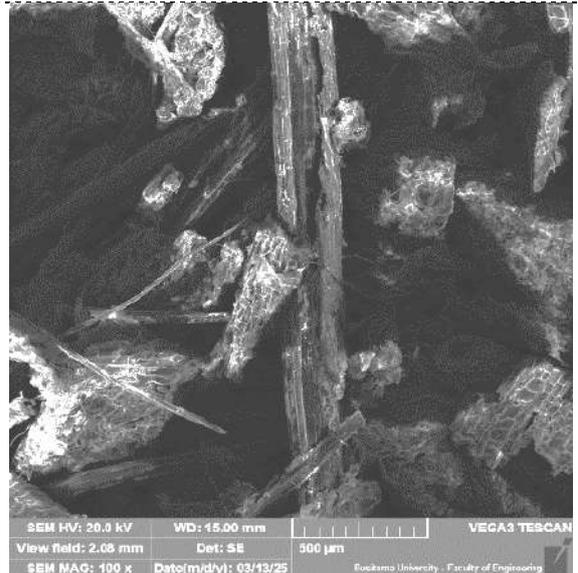


Fig. 11. Waste powder micrograph under 500µm using SEM

Elemental analysis was done on uncarbonated pseudostem waste using energy-dispersive X-ray, in which oxygen was found to be 46.3%, Potassium 5.0%, Hydrogen 5.8%, Calcium 1.2% and Carbon 41.7%. Neither nitrogen nor sulphur was seen in the feedstock despite their common presence in a variety of other biomass materials.

2.1.2 Cassava peels processing

Cassava peels were obtained from the Eastern parts of Uganda. They were sorted by removing those with tubers and sun-dried. The dry cassava peels were cut into small pieces and milled using a grain milling machine. Figure 7 shows sun-drying and milled powder ready for use.



Fig. 12. Cassava peels sun-drying



Fig. 13. Cassava peels powder

2.2 Pyrolysis

2.2.1 Oven development

In preparation for the pyrolysis of banana pseudo-stem waste, an oven made of AISI 304 grade of stainless-steel measuring 18cm bore and 14cm depth, complete with a lockable lid, was fabricated using a 1.5mm thick sheet. The lid was provided with a central hole for use in temperature measurement and also as a breather during the pyrolysis process. This oven goes to a 20-liter jerrican six times, giving room for variation of pyrolysis parameters where needed. Figure 14 and 15 illustrates sheet rolling process and a complete oven ready for use.



Fig. 14. Oven fabrication



Fig. 15. Oven complete with lid

2.2.2 Pyrolysis

Locally made domestic charcoal jiko was used for heating, using charcoal from the local market. Full heat capacity was maintained for four hours, during which a maximum of 300 °C was recorded. Gradual cooling was allowed until all the burning charcoal ceased, and an additional natural cooling at atmospheric temperature of 21.5 °C for two hours. Figures 16 and 17 illustrate the material packing and pyrolysis process set up.

The oven was tightly packed full of banana pseudostem waste using the lockable lid before heating commenced. Fumes generated during the process were allowed to escape through the vent provided. A total of 2 kilograms of charcoal from the local market were used in the carbonation process.



Fig. 16. Oven stuffing for pyrolysis



Fig. 17. Pyrolysis using local charcoal jiko

2.2.3 Briquette production

Proportions of cassava peel powder was measured in amounts of 10%, 15% and 20% of the feedstock by weight. It was then boiled in water and then added into a blender together with the carbonated banana pseudostem waste. Boiling cassava peels binder using a local jiko and charcoal is shown in figure 18. Blending operation of the mixture using electrically powered blender is shown in figure 19. Effective blending facilitates uniform binding action when appropriate briquetting load is applied.

The mould measuring 40mm bore and 100mm deep for briquetting was fabricated using mild steel with hinges and an easy lock system for ease of release. Briquetting loads applied in the experiments are; 10kg, 15.2kg, 24.5kg and 49.5kg. Briquetting was conducted using hydraulic training equipment at the hydraulics lab in the technical university of Kenya shown in figure 20. Drying of the briquettes made was done in open place in the sun under ambient conditions in Nairobi Kenya as shown in figure 21.



Fig. 18. Cassava peels powder boiling



Fig. 19. Carbonated waste and binder blending

The mixture from the blender was manually fed into a mould on a modified hydraulic training equipment for compaction at the Technical University of Kenya hydraulics lab. Several samples were made at varied loads for comparison on mechanical and thermal properties. The produced samples were sun-dried for four days of eight hours each in preparation for physical, mechanical, and thermal analysis.

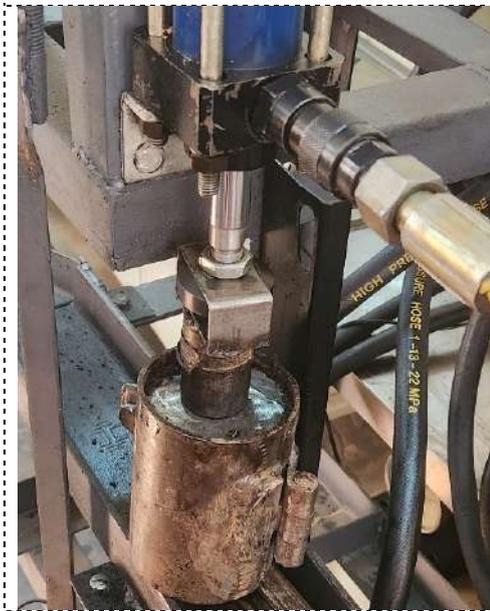


Fig. 20. Briquetting operation



Fig. 21. Sun-drying of briquettes

3. Results and Discussion

3.1 Results

A number of samples have been produced, where samples with 0% binder content are labelled A0, those with 10% binder content, A1, 15% are labelled B1, and 20% C1. Each category is further divided into four categories according to the compaction load in kilograms used. Table 1 shows the sample nomenclature used.

Table 1

Actual coding of results

Binder %	10kg	15.2kg	24.5kg	49.5kg
0% (A0)	A01	A02	A03	A04
10% (A1)	A11	A12	A13	A14
15% (B1)	B11	B12	B13	B14
20% (C1)	C11	C12	C13	C14

3.1.1 Moisture content

Four samples were subjected to moisture content analysis. Test specimens were heated to a constant mass in an air oven at a temperature of 105°C according to Kenya standard KS 2912: 2020 on solid biofuels. The percentage moisture content was calculated from the loss of mass in the test specimen. An average moisture content of 8.8% was obtained from A03, B12, C13, and C14 samples.

3.1.2 Mass density

Samples C14 was made of 65mm diameter mould whereas C13 & B12 had an equal diameter of 40mm. Their lengths and weights were 65mm, 18.85g for C13 while B12 was 55mm, 15.97g. C14 had a density of 512 kg/m³, C13 a density of 231.71kg/m³ while B12 had a density of 231.88kg/m³. Sample A03 collapsed after drying, and, therefore, no density was calculated.

3.1.3 Burning rate and calorific value

A mass of 185 grams comprising A13, B12, C13, and C14 samples was packed onto a local charcoal jiko and lit just like charcoal. These briquettes boiled the water and continued to evaporate 1kg of water for 27 minutes. Applying equation 7, the burning rate was found to be 6.85g/min. When tested on the combustion calorimeter model e2k, the calorific value for the samples was found to be 8.172MJ/Kg. Figure 22 and figure 23 illustrates the experimental setup for burning rate and heat utilization efficiency experiments.

3.1.4 Heat utilization efficiency

Considering equation 8, the mass of cold water was 1kg, the temperature of cold water was 20.5 °C, the boiling temperature was 96.5 °C in Nairobi, 1795m above sea level, the mass of steam generated was 470g, while the mass of briquettes burnt was 185g. Taking the specific heat capacity of water of 4.184 kJ/Kg °C and the latent heat of vaporization of water at 100 °C to be 2260KJ/Kg. Since the calorific value of the briquettes was found to be 8.172MJ/Kg using the combustion calorimeter model e2k, then applying equation 8, the heat utilization efficiency was found to be 91%.

3.1.5 Mechanical strength

Samples B12, C13, and C14 were tested for compressive strength using the Testometric Material Testing Machine at Busitema University where B12 was found to be 0.829MPa, C13 was 0.831MPa, and C14 was 0.825MPa.



Fig. 22. Burning rate test for the briquettes



Fig. 23. Heat utilization efficiency set-up

3.1.6 Volatile matter and ash content

Samples C14, C13 and B12 were analysed at the Kenya Bureau of Standards against KS 2912:2020, the Kenya standard on solid biofuels. The ash content was found to be 17.22%, moisture content was 8.8% and volatile matter 29.96%.

3.1.7 Fixed carbon

Using equation 4, the fixed carbon was found to be 44.98%. A summary of experimental results obtained are tabled in table 2.

Table 2
 Summary of results and applicable standard/reference

PARAMETERS	RESULTS	REQUIREMENTS	STANDARD/REFERENCE
Moisture content	8.8%	27% Max	KS 2912
Volatile matter	29.96%	10% Max	KS 2912
Ash content	17.22%	25% Max	KS 2912
Fixed carbon	44.98%	44% Min	KS 2912
Bulk density	232kg/m ³	(1000-1400) kg/m ³	DIN 51731, [31]
Calorific value	8.172MJ/Kg	18MJ/Kg Min	KS 2912
Burning rate	6.85g/Min	Literature	[30, 31]
Heat utilization efficiency	91%	Literature	[30]

3.2 Discussion

Elemental analysis of uncarbonated pseudostem waste gave a carbon content of 41.7%. The lack of nitrogen and Sulphur elements in the material is a promising indicator that banana pseudostem waste is indeed a rich source of clean alternative source of energy. Mechanical strength and environmental factors determine the efficacy of bio-fuels. It therefore means that with mechanical strength of 0.828MPa, a heat utilization efficiency of 91% and the lack of nitrogen and sulphur in the material, then banana pseudostem waste bio-briquettes perform highly as a clean environmentally friendly fuel. A burning rate of 6.85g/min in this research is better than that of cashew nut shells briquettes with 11.90 g/min and corncobs briquettes with 9.7g/min reported in literature.

Cassava peels binder has also proven to be an effective and suitable binder based on the thermal and mechanical properties obtained from the current research. They are cheap, readily available, environmentally friendly and have not shown any evidence of interference to combustion performance. It is evident that the cassava peels binder is effective since the samples A03 which were made with 0% binder content collapsed after drying.

Based on the Kenya standard KS 2912:2020 on solid biofuel, the ash content, moisture content and fixed carbon are within the required limits. However, the volatile matter is 29.96% instead of 25% maximum, and calorific value of 8.172MJ/Kg against a minimum requirement of 18MJ/Kg. On briquette density, the Kenya standard KS 2912:2020 on solid biofuel does not give a specific value for either commercial or domestic whereas German standard DIN 51731 requires a density of between (1000-1400) kg/m³ for commercial use briquettes. Existing literature shows density ranges of agricultural residue briquettes being less than 1000kg/m³ apart from briquettes whose feedstock is wood charcoal.

4. Conclusions

The main objective of production and characterization of bio-briquettes from 100% banana pseudostem waste feedstock and cassava peels binder, an environmentally friendly fuel was achieved in this research. Huge amounts of banana pseudostem waste obtained from mechanical decortication is now capable of being converted into clean environmentally friendly bio-fuel through drying, pyrolysis, and compaction of material mixed with cassava peels binder which is otherwise a cassava plant waste. Implementation of the current research findings will go a long way in reducing agricultural waste, provision of clean energy, enhancement of food security and support of circular economy practices in sub-Saharan Africa.

The burning rate of 6.85g/min and the heat utilization efficiency of 91% achieved in this research indicate the high thermal potential of banana pseudostem waste briquettes achieved in this research compared to other reported results in literature. It was also proven that choice of cassava peels as binder was both sustainable and suitable from strength and density results achieved when compared with samples without binder in them.

This research was based in Uganda, Kenya and the East African region where electrical energy for drying, pyrolysis and compaction is scarce and costly. In addition, these processes are energy intensive in nature. Therefore, one challenge was cost of energy needed to produce sustainable and competitive bio-briquettes from banana pseudostem waste feedstock and cassava peels binder. It is therefore recommended that a more sustainable energy source be used for drying, pyrolysis and compaction processes such as the readily available solar energy. On parameters such as volatile matter, density and calorific value which are below the required level for commercial applications, it is recommended that more research be done on ways of improving the parameters while maintaining the environmental friendliness and sustainability of the bio-briquettes.

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Conflict of interest

The authors declare that there is no conflict of interest regarding the publication of this paper. No financial support, grants, or other forms of compensation were received that could have influenced the outcomes of this work.

Author Contribution

Dr. Fredrick Mutua and Dr. Edwin Kamalha participated in conceptualization, funding acquisition, and day-to-day guidance during the research process. Professor Alex Muumbo participated in the review of this paper, supervision of the work, and editing. Moses Gichana participated in material preparation, lab work, drafting, corrections and submission of the paper. All authors read and approved the manuscript for submission.

Data Availability Statement

All data generated during this study are included in this published article. Additional data sets are available from the corresponding author upon reasonable request. Where applicable, publicly available datasets used in the study are cited in the references.

References

- [1] Asamoah, Bernice, Josiane Nikiema, Solomie Gebrezgabher, Elsie Odonkor, and Mary Njenga. "A review on production, marketing and use of fuel briquettes." (2016). <https://doi.org/10.5337/2017.200>
- [2] Brand, Martha Andreia, Ailton Leonel Balduino Junior, Daniela Leticia Nones, and Angela Zakostelsky Neves Gaa. "Potential of bamboo species for the production of briquettes." *Pesquisa Agropecuária Tropical* 49 (2019): e54178. <https://doi.org/10.1590/1983-40632019v4954178>
- [3] Marreiro, Hívila MP, Rogério S. Peruchi, Riuzuani MBP Lopes, Sílvia LF Andersen, Sayonara A. Eliziário, and Paulo Rotella Junior. "Empirical studies on biomass briquette production: A literature review." *Energies* 14, no. 24 (2021): 8320. <https://doi.org/10.3390/en14248320>
- [4] Sanchez, Philip DC, Mia MT Aspe, and Kenneth N. Sindol. "An overview on the production of bio-briquettes from agricultural wastes: methods, processes, and quality." *Journal of Agricultural and Food Engineering* 1, no. 0036 (2022): 2716-6236.
- [5] Sweya, Lukuba N., Nyangi T. Chacha, and Joshua Saitoti. "Briquette quality assessment from corn husk, bagasse, and cassava roots using banana peels, wastepaper, and clay soil as binders." *Environmental Quality Management* 33, no. 3 (2024): 47-59. <https://doi.org/10.1002/tqem.22052>
- [6] Nonsawang, Siwakorn, Suchat Juntahum, Pasawat Sanchumpu, Wiriya Suaili, Kritsadang Senawong, and Kittipong Laloon. "Unlocking renewable fuel: Charcoal briquettes production from agro-industrial waste with cassava industrial binders." *Energy Reports* 12 (2024): 4966-4982. doi: <https://doi.org/10.1016/j.egyr.2024.10.053>.
- [7] Saraiva, B., E. B. V. Pacheco, L. Lea Yuan Visconte, E. Pereira Bispo, V. Alves Escócio, AM Furtado de Sousa, A. Gomes Soares, M. Freire Junior, L. C. D. C. Motta, and G. F. D. C. Brito. "Potentials for utilization of post-fiber extraction waste from tropical fruit production in brazil—the example of banana pseudo-stem." *International Journal of Environment and Bioenergy* 4, no. 2 (2012): 101-119.
- [8] Sahoo, Diptiprakash, and Neelancherry Remya. "Influence of operating parameters on the microwave pyrolysis of rice husk: biochar yield, energy yield, and property of biochar." *Biomass Conversion and Biorefinery* 12, no. 8 (2022): 3447-3456. <https://doi.org/10.1007/s13399-020-00914-8>
- [9] Bongers, Ghislaine, Laurence Jassogne, Ibrahim Wanyama, Analet Nibasumba, David Mukasa, and P. van Asten. "Understanding and exploring the evolution of coffee-banana farming systems in Uganda." (2012): 20133410286.
- [10] Sato, Yasuaki, Kaori Komatsu, Koichi Kitanishi, Kagari Shikata-Yasuoka, and Shingo Odani. "Banana farming, cultivars, uses, and marketing of Nkore in southwestern Uganda." *Tropical Agriculture and Development* 62, no. 3 (2018): 141-149.
- [11] Menya, Emmanuel, Collins Okello, Henning Storz, Joel Wakatuntu, Medard Turyasingura, David K. Okot, Simon Kizito et al. "A review of progress on torrefaction, pyrolysis and briquetting of banana plant wastes for biofuels." *Biomass conversion and biorefinery* 15, no. 9 (2025): 13227-13269. <https://doi.org/10.1007/s13399-024-06204-x>
- [12] Okuthe, Grace. "Valorizing fruit and vegetable waste: The untapped potential for entrepreneurship in sub-Saharan Africa—A systematic review." *Recycling* 9, no. 3 (2024): 40. <https://doi.org/10.3390/recycling9030040>
- [13] Velusamy, Sampathkumar, Anandakumar Subbaiyan, and Ramesh Srikrishnaperumal Thangam. "Combustion characteristics of briquette fuels from sorghum panicle–pearl millets using cassava starch binder." *Environmental Science and Pollution Research* 28, no. 17 (2021): 21471-21485. <https://doi.org/10.1007/s11356-020-11790-0>
- [14] Hu, Zhong-Ting, Yin Ding, Yuchao Shao, Luxiang Cai, Zi-Yan Jin, Zifeng Liu, Jia Zhao et al. "Banana peel biochar with nanoflake-assembled structure for cross contamination treatment in water: Interaction behaviors between lead and tetracycline." *Chemical Engineering Journal* 420 (2021): 129807. doi: <https://doi.org/10.1016/j.cej.2021.129807>.
- [15] Arachchige, U. S. P. R. "Briquettes production as an alternative fuel." *Nature Environment and Pollution Technology* 20, no. 4 (2021): 1661-1668. <https://doi.org/10.46488/NEPT.2021.v20i04.029>
- [16] Waheed, M. A., O. A. Akogun, and C. C. Enweremadu. "Influence of feedstock mixtures on the fuel characteristics of blended cornhusk, cassava peels, and sawdust briquettes." *Biomass Conversion and Biorefinery* 13, no. 17 (2023): 16211-16226. <https://doi.org/10.1007/s13399-023-04039-6>

- [17] Lomunyak, George, Booker Osodo, Francis Njoka, and Emmanuel Kombe. "Characterization, optimization and emission analysis of manually-made charcoal dust briquettes with starch, paper and algae binders." *Heliyon* 10, no. 24 (2024). <https://doi.org/10.1016/j.heliyon.2024.e40991>
- [18] Kpalo, Sunday Yusuf, Mohamad Faiz Zainuddin, Latifah Abd Manaf, and Ahmad Muhaimin Roslan. "A review of technical and economic aspects of biomass briquetting." *Sustainability* 12, no. 11 (2020): 4609. <https://doi.org/10.3390/su12114609>
- [19] Al-Rumaihi, Aisha, Muhammad Shahbaz, Gordon McKay, Hamish Mackey, and Tareq Al-Ansari. "A review of pyrolysis technologies and feedstock: A blending approach for plastic and biomass towards optimum biochar yield." *Renewable and Sustainable Energy Reviews* 167 (2022): 112715. doi: <https://doi.org/10.1016/j.rser.2022.112715>.
- [20] Xie, Yanqi, Liang Wang, Hailong Li, Lena Johansson Westholm, Lara Carvalho, Eva Thorin, Zhixin Yu, Xinhai Yu, and Øyvind Skreiberg. "A critical review on production, modification and utilization of biochar." *Journal of Analytical and Applied Pyrolysis* 161 (2022): 105405. doi: <https://doi.org/10.1016/j.jaap.2021.105405>.
- [21] Ngene, Gloria Ifunanya, Bénit Bouesso, María González Martínez, and Ange Nzihou. "A review on biochar briquetting: Common practices and recommendations to enhance mechanical properties and environmental performances." *Journal of Cleaner Production* 469 (2024): 143193. doi: <https://doi.org/10.1016/j.jclepro.2024.143193>.
- [22] Zhang, Guojie, Yinghui Sun, and Ying Xu. "Review of briquette binders and briquetting mechanism." *Renewable and Sustainable Energy Reviews* 82 (2018): 477-487. doi: <https://doi.org/10.1016/j.rser.2017.09.072>.
- [23] Samomssa, Inna, Yvette Jiokap Nono, Geta Cârâc, Gheorghe Gurău, Mihaela Rodica Dinică, and Richard Kamga. "Optimization of fuel briquette production from cassava peels, plantain peels and corn cobs." *Journal of Material Cycles and Waste Management* 23, no. 5 (2021): 1905-1917. <https://doi.org/10.1007/s10163-021-01260-1>
- [24] Narzary, Anjali, Jackie Brahma, and Amarendra K. Das. "Utilization of waste rice straw for charcoal briquette production using three different binder." *Cleaner Energy Systems* 5 (2023): 100072. doi: <https://doi.org/10.1016/j.cles.2023.100072>.
- [25] Fronza, Pâmella, Ana Letícia Rodrigues Costa, Adriana Silva Franca, and Leandro Soares de Oliveira. "Extraction and characterization of starch from cassava peels." *Starch-Stärke* 75, no. 3-4 (2023): 2100245. <https://doi.org/10.1002/star.202100245>
- [26] Okot, David K., Paul E. Bilsborrow, and Anh N. Phan. "Effects of operating parameters on maize COB briquette quality." *Biomass and bioenergy* 112 (2018): 61-72. doi: <https://doi.org/10.1016/j.biombioe.2018.02.015>.
- [27] Dyjakon, Arkadiusz, Łukasz Sobol, Mateusz Krotowski, Krzysztof Mudryk, and Krzysztof Kawa. "The impact of particles comminution on mechanical durability of wheat straw briquettes." *Energies* 13, no. 23 (2020): 6186. <https://doi.org/10.3390/en13236186>
- [28] Kongprasert, Nattapong, Pilada Wangphanich, and Anuwat Jutilarptavorn. "Charcoal briquettes from Madan wood waste as an alternative energy in Thailand." *Procedia Manufacturing* 30 (2019): 128-135. doi: <https://doi.org/10.1016/j.promfg.2019.02.019>.
- [29] Akogun, Opeyemi A., M. Adekojo Waheed, Salami O. Ismaila, and Olawale U. Dairo. "Co-briquetting characteristics of cassava peel with sawdust at different torrefaction pretreatment conditions." *Energy Sources, Part A: Recovery, Utilization, and Environmental Effects* 46, no. 1 (2024): 5768-5786. <https://doi.org/10.1080/15567036.2020.1752333>
- [30] Sawekwiharee, Sangwoei, Thanaporn Boonchoo, Anchana Kuttiyawong, and Naphat Chathirat. "Heating energy briquettes from Cashew nut shell." *Applied Mechanics and Materials* 804 (2015): 283-286. doi: 10.4028/www.scientific.net/AMM.804.283.
- [31] Nurba, D., M. Yasar, Mustaqimah, R. Fadhil, S. P. Sari, and C. V. Mysa. "Performance of Corncobs and Wood Charcoal Briquette as Heat Energy Sources in In-Store Dryer." In *IOP Conference Series: Earth and Environmental Science*, vol. 365, no. 1, p. 012048. IOP Publishing, 2019. <https://doi.org/10.1088/1755-1315/365/1/012048>