

Characterization of briquettes developed from banana peels, pineapple peels and water hyacinth

Tadeo Mibulo

Makerere University

Denis Nsubuga

Makerere University

Isa Kabenge (✉ isakabenge@gmail.com)

Makerere University

Kerstin D. Wydra


Erfurt University of Applied Sciences

Research Article

Keywords: Briquettes, calorific value, banana peels, pineapple peels and water hyacinth

Posted Date: June 2nd, 2022

DOI: <https://doi.org/10.21203/rs.3.rs-1708394/v1>

License:  This work is licensed under a Creative Commons Attribution 4.0 International License. [Read Full License](#)

Abstract

Background: Uganda's energy needs are heavily reliant on biomass sources. This dependency of Uganda's burgeoning population on biomass for household and commercial purposes is posing pressure on natural resources such as forests. This study was carried out to investigate the utilization of some of the country's highly produced agricultural waste for the creation of biofuels.

Methods: Pineapple peels, banana peels and water hyacinth were utilized for generation of both carbonized and uncarbonized briquettes. Physical properties and calorific values for the developed briquettes were determined through thermogravimetric analysis and using a bomb calorimeter.

Results and conclusion: Pineapple peel carbonized briquettes had the highest calorific value (25.08 MJ/kg) followed by a composite of banana peels and pineapple peels (22.77 MJ/kg). The moisture content for briquettes ranged between 3.9 to 18.65%. Uncarbonized briquettes had higher volatile matter (ranging between 62.83 and 75.1%) than carbonized briquettes (ranging between 22.01 and 24.74%). Uncarbonized briquettes had shorter boiling time (ranging between 27 and 36 minutes for 2.5 liters) than carbonized briquettes (ranging between 26 and 41 minutes). Water hyacinth alone produced briquettes with low calorific values (16.22 MJ/kg), however, calorific values increased when mixed with banana (20.79 MJ/kg) or pineapple peels (20.55 MJ/kg). The findings reveal crucial information on how agricultural wastes might be used to augment the energy sources pool in order to protect the environment and creating social stability in the community.

Introduction

Uganda's energy needs are skewed toward biomass consumption, which accounts for more than 90% of the country's needs. Wood accounts for 70% of biomass consumption, charcoal for 16%, and agricultural waste for 4% [1–3]. Other energy sources include fossil fuels which make up 5% and hydroelectricity with only 5% from two large dams and small hydro projects. Such reliance on biomass fuels, along with Uganda's fast population increase, has put significant constrain on natural resources, particularly forests. With a total forest coverage of 9%, Uganda has lost 15% of its forest estates in the previous 25 years, standing for about 3.06 million of lost hectares, from 4.88 million ha in 1990 to 1.82 million ha in 2015 [4]. This has greatly contributed to the irregular and rampant soil erosion, as well as the non-uniform and erratic rainfall distribution [5] and to social impacts like poverty [6]. Uganda's population has continued to grow rapidly to approximately 43 million people in 2022 [7]. In 2019, over 76 percent of Uganda's population did not have access to the national grid, making biomass production of wood fuels a key source of fuel [8]. Wood fuels are also being used in small-scale businesses such as brick and tile manufacture, agro-processing, and seafood processing [6].

Considering that agriculture is still the most widely practiced economic activity in Uganda [9], by-products and/or wastes can be utilized for energy generation [2, 10]. The produced energy is used for domestic culinary duties while also contributing to the agricultural waste reduction and disposal system in use. Leaving these agricultural wastes to degrade is typical practice, and they are occasionally used to enhance animal diets in subsistence farms [10–13]. Uganda's banana fruit processing alone is estimated to generate more than 4.3 MT of banana waste annually [9]. Kayunga district, one of the leading pineapple producing districts in Uganda produce approximately 15,960 tons of pineapple in a single season [14], of which 80% is waste. The waste can sustainably be utilized through converting this organic material into briquettes [10, 15, 16]. Water hyacinth, a water weed causes interference to human activities, adversely affecting flora and fauna in lakes and rivers, and hence is considered as a noxious weed [17, 18]. One of the potential solutions is its utilization for energy generation. Water hyacinth has been evaluated for production of briquettes [19], therefore it can provide a co-substrate for briquettes with banana peels or pineapple peels. Briquettes are produced using both low- and high-pressure techniques, hence are affordable to the local people, and can be used to partially substitute the use of firewood and charcoal.

Briquettes are eco-friendly, energy-efficient low technology fuel, and also a cleaner energy source used for daily cooking compared to wood fuels which are often linked to indoor pollution and its related health problems [20]. A shift to a more sustainable alternative of prevailing Uganda's energy system to primarily support domestic cooking applications is beneficial and crucial in activating and promoting long-term conscientious alleviation of environmental degradation and reducing impact on climate change [20, 21]. The study assessed the suitability of utilizing banana peels and pineapple peels blended with water hyacinth for briquette generation.

Materials And Methods

Material source and preparation

Banana peels and pineapple peels were collected from local farmers in Kayunga districts (0.5817° N, 33.0294° E). Water hyacinth was collected from Lubigi water stream (0.3472° N, 33.546° E), flowing at the boundaries of Kampala and Wakiso districts to Makerere University Agricultural Research Institute Kabaanyolo (MUARIK) (0.4683° N, 32.6074° E) for drying and briquettes production. The collected substrates were sundried for two weeks to reduce the moisture content to about 15% wb.

Briquette production

The study considered two kinds of briquettes; carbonized and uncarbonized. Uncarbonized briquettes production started after the materials were dried while materials for carbonized briquettes were carbonized first as described in the section 2.2.1 below.

Carbonization

Prior to producing briquettes, two thirds of the dried banana peels, pineapple peels and water hyacinth were carbonized using slow pyrolysis [23]. The process was carried out using a locally fabricated carbonizer. The carbonizer was made from a steel drum of 200-liter volume capacity with a height of 1m and a diameter of 0.5m. The dried substrates were loaded into the drum, ignited using a lighter fire and the drum was covered for 50 minutes, to control air available for complete combustion inside the carbonizer. After the carbonization process, the biochar was removed from the drum and ground into fine particles to allow more contact with the binder. The rest of the substrates were kept uncarbonized.

Starch binder

A paste was prepared from 400g of cassava flour and 3 liters of cold water at 25°C and thereafter poured into 4.5 liters of boiling water at a temperature of 100°C. Continuous mixing was done to produce a good binder with more water and less stickiness. In the final mixture of the required binder, water could disperse without any clumps of flour, which took 10 min.

Briquetting

One liter of produced starch binder was mixed in each of the substrate combination (Table 1) for both carbonized and uncarbonized substrates and mixed thoroughly to obtain a composite mixture. Each mixture was filled in the mold with nine slots each having 40 mm outer diameter, 15 mm inner diameter and 52 mm height, and placed on to the pressing hydraulic machine, (Model: HHP-60) for compaction. The maximum compaction pressure was regulated was 100 MPa which was regulated with a pressure gauge inserted at the pressing point of the machine purposely to prevent the binder from radiating out of the mold.

Table 1
Substrate mixing ratios

Treatment	Banana peels (BP)	Pineapple peels (PP)	Water hyacinth (WH)
T1	1	0	0
T2	0	1	0
T3	0	0	1
T4	1	1	0
T5	1	0	1
T6	0	1	1
T7	1	1	1
T8	1	2	2

1.1 Evaluation of briquettes' properties

Thermo-gravimetric analysis

Physical and chemical properties which include moisture content, ash content, fixed carbon, and volatile matter of the substrates, were determined using an Eltra ThermoSTEP non-isothermal Thermo gravimetric analyzer (TGA), Haan, Germany according to ASTM-D7582-15 [24]. TGA experiments' temperatures varied from room temperature to 920°C at a heating rate of 16°C/min. Prior to TGA experimentation, compressed air of high purity (oxygen: nitrogen = 21:79, > 99.5%) was used to clean the crucibles and chamber. The flow rate was maintained at 1 l/min and the average mass of the samples used was 1.1 g

Calorific value determination

The calorific values for the produced briquettes were determined using an IKA C 2000 oxygen bomb calorimeter. The briquettes developed from banana peels, pineapple peels and water hyacinth were prepared to fit into the holdings of the calorimeter. Approximately 1 g of developed briquette was placed in a nickel crucible and fired inside the bomb calorimeter using an ignition wire in the presence of oxygen. The calorimeter produced readings on the screen in about 30 minutes.

Water boiling test

The water boiling test was used to determine the efficiency of the developed briquettes for the cooking function. The test was carried out using 250 g of briquettes to boil 2.5 liters of water in an improved stove. The boiling temperatures were monitored using a thermometer, until the temperatures were constant. The taken to reach the constant temperature was recorded using a time watch.

Statistical analysis

Substrate characteristics and Briquette quality attributes for different substrate combinations were statistically analyzed using R Software. One-Way ANOVA with Tukey's post-hoc analysis was used to assess the differences between mean values of different briquettes qualities for these combinations. A paired sample t-test was used between uncarbonized and carbonized briquette samples to determine the effect of carbonization. All tests for significance were conducted at a 0.05 significance level.

Results And Discussion

Physical properties for briquettes

Moisture content

The mean moisture content was determined for the briquettes produced from different substrate combination (Table 2). The moisture content for each nominal category (uncarbonized and carbonized) was significantly different ($p \leq 0.05$). The single substrate-based briquette samples had lower moisture content compared to the composite ones. The moisture content of briquette samples agrees with those recommended (5–15%) [25] for good and quality briquettes except for composite uncarbonized briquette samples, pineapple peels and water hyacinth briquette samples. A paired statistical t-test showed a significant difference ($p = 0.003$) in the moisture content between uncarbonized and carbonized briquettes. The moisture content was lower in carbonized briquettes than in uncarbonized briquettes because the hydrophilic hydroxyl group is destructed [26]. The carbonization process helps in reducing absorption of moisture, which is a necessary aspect for increased shelf life and storage of the briquettes, preventing rotting and decomposition [26, 27]. High moisture content in briquettes results in swelling and disintegration [28] and interferes with thermo-chemical conversion processes. During combustion, a section of the energy is used to evaporate the water, leading to low heating values and thus reducing the overall energy efficiency of the briquettes [29]. Additionally, high moisture content in biomass fuels leads to increased production of green-house gases due to incomplete combustion [30].

Table 2
Moisture content for uncarbonized and carbonized briquettes

Substrate combination	Uncarbonized (%)	Carbonized (%)
BP	8.30 ^b ± 0.159	5.32 ^d ± 0.052
PP	6.65 ^a ± 0.114	4.21 ^b ± 0.046
WH	7.30 ^a ± 0.027	3.90 ^a ± 0.058
BP : PP - 1:1	9.93 ^c ± 0.432	5.96 ^e ± 0.100
BP : WH - 1:1	17.34 ^e ± 0.352	5.01 ^c ± 0.05
PP : WH - 1:1	18.65 ^f ± 0.279	5.072 ^{cd} ± 0.138
BP : PP : WH - 1:1:1	13.91 ^d ± 0.171	4.25 ^b ± 0.133
BP : PP : WH - 1:2:2	16.75 ^e ± 0.338	5.92 ^e ± 0.194
Means in the same column with different superscripts are significantly different at $p \leq 0.05$		

Volatile matter

The volatile matters for both uncarbonized and carbonized briquette samples were significantly different ($p \leq 0.05$) (Table 3). For uncarbonized samples, the banana peels briquettes had the highest volatile matter (75.1%), while for carbonized samples the composite of the three substrates (banana peels, pineapple peels and water hyacinth) in proportions of 1:2:2 had the highest volatiles (24.74%) and water hyacinth the lowest (22.01%). The carbonized sample briquettes had a lower volatile matter percentage compared to the uncarbonized sample briquettes. A paired sample statistical t-test showed a significant difference ($p = 0.001$) between uncarbonized and carbonized briquette sample pairs. This was similar to results obtained by Deshannavar et al. [31] on rice husk and rice husk char. Low volatile matter implies that the ignitability of the briquettes will be reduced, but once they ignite, then combustion will produce little or no smoke with a clean flame [32]. The results were similar to those obtained by [33] when using banana peels and banana bunch waste.

Table 3
Volatile matter for uncarbonized and carbonized briquettes

Substrate combination	Uncarbonized	Carbonized
BP	75.10 ^e ± 1.066	22.79 ^{abc} ± 0.482
PP	72.61 ^d ± 0.784	24.36 ^{cd} ± 0.840
WH	68.97 ^c ± 0.491	22.01 ^a ± 0.432
BP : PP - 1:1	69.93 ^c ± 0.475	23.12 ^{abcd} ± 0.490
BP : WH - 1:1	62.83 ^a ± 0.167	22.5 ^{ab} ± 0.175
PP : WH - 1:1	62.56 ^a ± 0.286	24.08 ^{bcd} ± 0.233
BP : PP : WH - 1:1:1	66.30 ^b ± 0.419	23.60 ^{bcd} ± 0.606
BP : PP : WH - 1:2:2	66.37 ^b ± 0.410	24.74 ^d ± 0.965
Means in the same column with different superscripts are significantly different at $p \leq 0.05$		

Ash content

The ash content for uncarbonized and carbonized briquette samples are shown in Table 4. There was a significant difference ($p \leq 0.05$) between different substrate combinations for both nominal variables. Water hyacinth briquette samples had the highest ash content, with 10.91% and 36.11% for uncarbonized and carbonized samples, respectively. A paired sample statistical t-test had a significant difference ($p = 0.001$); carbonized briquettes of all samples had more ash content than the uncarbonized briquettes, revealing the effect of carbonization. Ash is incombustible; therefore, it does not provide useful energy in domestic cooking applications rendering briquettes of minor quality [34]. Composite briquettes had higher ash content than single substrate briquettes. Lubwama et al. [35] reported similar results on rice husks, coffee husks and ground nut shells. Development of bio-composite briquettes had a net positive impact on ash content levels which consequently lower their calorific values.

Table 4
Ash matter for uncarbonized and carbonized briquettes

Substrate combination	Uncarbonized	Carbonized
BP	2.63 ^a ± 0.809	20.73 ^c ± 0.320
PP	3.63 ^a ± 0.331	12.54 ^a ± 0.396
WH	10.19 ^c ± 0.161	36.11 ^e ± 0.375
BP : PP - 1:1	6.01 ^b ± 0.064	17.02 ^b ± 2.129
BP : WH - 1:1	6.32 ^b ± 0.187	27.43 ^d ± 0.143
PP : WH - 1:1	6.58 ^b ± 0.143	22.70 ^c ± 0.191
BP : PP : WH - 1:1:1	6.126 ^b ± 0.207	22.12 ^c ± 0.190
BP : PP : WH - 1:2:2	2.89 ^a ± 0.470	20.96 ^c ± 0.609
Means in the same column with different superscripts are significantly different at $p \leq 0.05$		

Fixed carbon

Pineapple peels had a higher percentage of fixed carbon for both uncarbonized (17.12%) and carbonized (58.89%) briquette samples (Table 5). A paired sample statistical t-test showed that carbonized briquettes had a significantly higher ($p = 0.001$) fixed carbon content than uncarbonized briquettes. This is attributed to the carbonization process [32], which tends to reduce the moisture and volatile content resulting in an increase in the fixed carbon [36]. Higher values of fixed carbon represent higher values of calorific value for the developed bio-composite briquettes [37].

Table 5
Fixed carbon for uncarbonized and carbonized briquettes

Substrate combination	Uncarbonized	Carbonized
BP	13.97 ^b ± 0.826	51.16 ^{de} ± 0.564
PP	17.12 ^c ± 0.379	58.89 ^f ± 0.496
WH	13.55 ^b ± 0.466	37.98 ^a ± 0.584
BP : PP - 1:1	14.13 ^b ± 0.049	53.90 ^e ± 2.716
BP : WH - 1:1	13.50 ^b ± 0.373	45.05 ^b ± 0.188
PP : WH - 1:1	12.21 ^a ± 0.379	48.15 ^c ± 0.154
BP : PP : WH - 1:1:1	13.67 ^b ± 0.233	50.03 ^{cd} ± 0.683
BP : PP : WH - 1:2:2	13.98 ^b ± 0.133	48.38 ^{cd} ± 0.613
Means in the same column with different superscripts are significantly different at $p \leq 0.05$		

Calorific value for the briquettes

The calorific values for both uncarbonized and carbonized briquette samples are presented in Fig. 1. The results show that briquette samples with high fixed carbon had higher calorific values, as also reported by Deshannavar et al. [31] and Lubwama et al. [35]. The calorific values were significantly different ($p \leq 0.05$) between the different substrate combinations, and a paired statistical sample t-test between the uncarbonized and carbonized briquette samples was also significantly different ($p = 0.001$). The pineapple peels had the highest value for both carbonized (25.08MJ/Kg) and uncarbonized (17.02MJ/Kg). Generally, the single substrate briquettes had higher calorific values compared to the composite ones. However, compositing improved the heating values of water hyacinth which were very low when used alone. The calorific values obtained in this study agrees with those reported by Lubwama et al. [35] on bio-composite briquette developed from rice husks, coffee husks and groundnut shells (16.6–22.0 MJ/Kg), and Okia, Ndiema & Ahmed. [38] reported values between (16.22–21.59 MJ/Kg) for briquettes developed from water hyacinth, cow dung and charcoal dust.

Water boiling test

Results for the time it takes to boil 2.5 liters of water using 250 g of briquettes are shown in Fig. 2. Generally, uncarbonized briquettes with low calorific values had shorter boiling time (ranging between 27 and 36 minutes) than carbonized briquettes with higher calorific values (ranging between 26 and 41 minutes). Uncarbonized briquettes have a higher content of volatile matter, and during combustion the developed briquette ignites burned more readily and faster than briquettes with a lesser volatile matter content. The results obtained for banana peels agree with Tumutegyereize et al. [39] who recorded times of between 31.5 to 52.5 minutes to boil 8 to 10 liters of water in 2-liter intervals. A relationship between calorific values and water boiling times for the developed composite briquettes is provided in Fig. 3. Calorific value is considered to influence the boiling time [35]. However, according to this study calorific value alone does not influence the boiling time. The composite briquette of all the three substrates (banana peels, pineapple peels and water hyacinth) has a short boiling time, attributed to the combined volatile matter.

Conclusion

The study aimed at utilizing the available agricultural waste materials (banana and pineapple peels) and water hyacinth, a water weed, to generate energy for utilization in cooking as a substitute for wood and charcoal. A manual pressing machine was used to produce carbonized and uncarbonized briquettes. Pineapple peel briquettes emerged with the highest calorific value (25.08MJ/Kg) followed by a composite of banana peels and pineapple peels (22.77MJ/Kg). Water hyacinth when used individually produced briquettes with low calorific values, however, the values significantly improved when composited with banana or pineapple peels. The results provide vital information how water hyacinth, a most abundant substrate and water weed, can enhance energy provision when utilized for briquette production with banana and pineapple peels.

Declarations

Acknowledgement

The Federal Ministry of Food and Agriculture (BMEL) based on a decision of the Parliament of the Federal Republic of Germany via Federal Office for Agriculture and Food (BLE) is acknowledged for funding this work through Makerere University, Kampala (Uganda).

Authors' contributions

TM conceptualized the study, carried out the experiments, collected and analyzed the data and wrote the major parts of the paper. DN contributed to the methodological design, supervised and critiqued data collection and analysis. IK and KDW contributed to study conceptualization, revised the manuscript, and made the suggestions for improvement. All authors read and approved the final manuscript.

Funding

The study was funded by the Federal Ministry of Food and Agriculture (BMEL) of the Federal Republic of Germany through Makerere University Kampala (Uganda).

Availability of data and materials

Not applicable.

Ethics approval and consent to participate

Not applicable.

Consent for publication

All the authors agreed to publish the article.

Competing interests

The authors declare that there is no conflict of interest regarding the publication of this paper.

References

1. "Sector Brief Uganda: Renewable Energy," 2022. [Online]. Available: <https://www.giz.de/en/downloads/giz2022-en-sectorbrief-uganda-renewable-energy.pdf> [Accessed: 2 Feb 2022]
2. Fashina A, Mundu M, Akiyode O, Abdullah L, Sanni D, Ounyesiga L (2018) The Drivers and Barriers of Renewable Energy Applications and Development in Uganda: A Review. *J Clean Technologies* 1(1): 9–39. <https://doi.org/10.3390/cleantechnol1010003>
3. Kabyanga M, Balana BB, Mugisha J, Walekhwa PN, Smith J, Glenk K (2018) Economic potential of flexible balloon biogas digester among smallholder farmers: A case study from Uganda. *Renewable Energy* J 120: 392–400. <https://doi.org/10.1016/j.renene.2017.12.103>
4. MWE (Ministry of Water and Environment). "State of Uganda's Forestry," 2016. [Online]. Available: <https://www.mwe.go.ug/sites/default/files/library/2.3%20The%20status%20of%20the%20national%20tree%20cover%20in%20Uganda.pdf> [Accessed: 12 Aug 2021]
5. Bamwesigye D, Kupec P, Chekuimo G, Pavlis J, Asamoah O, Darkwah SA, Hlaváčková P (2020) Charcoal and wood biomass utilization in Uganda: The socioeconomic and environmental dynamics and implications. *J Sustainability* 12(20): 1–18. <https://doi.org/10.3390/su12208337>
6. Abigaba G, Niyibizi G, Turinayo Y, Nansereko S (2017) Implications of fuel wood scarcity on livelihoods of rural communities of Nyarubuye Sub-County in Kisoro District, south western Uganda. *Uganda Journal of Agricultural Sciences* 17(1): 43. <https://doi.org/10.4314/ujas.v17i1.5>
7. UBOS (Uganda Bureau of Statistics), "Population Clock," 2022. [Online]. Available: <https://www.ubos.org/> [Accessed: 30 Mar 2022]
8. Menno JVV (2020) An overview of recent developments and the current state of the Ugandan energy sector (Uganda's energy sector: A fiscal risk No. E-20046-UGA-1). London. Available: https://www.theigc.org/wp-content/uploads/2020/12/UGA-20046-Paper-1_IGC-project_Uganda-energy-sector_Fiscal-risk_state-of-the-energy-sector_25062020.pdf [Accessed: 30 Mar 2022]

9. UBOS (Uganda Bureau of Statistics), "Uganda Bureau of Statistics 2020 Statistical Abstract." [Online]. Available: https://www.ubos.org/wp-content/uploads/publications/11_2020STATISTICAL_ABSTRACT_2020.pdf [Accessed: 30 Aug 2021]
10. Nsubuga D, Banadda N, Kiggundu N (2019) Innovations in Value-Addition of Agricultural By-Products in Uganda. *Journal of Environmental Protection* 10: 1493–1506. <https://doi.org/10.4236/jep.2019.1011089>
11. Baidhe E, Kigozi J, Mukisa I, Muyanja C, Namubiru L, Kitarikawe B (2021) Unearthing the potential of solid waste generated along the pineapple drying process line in Uganda: A review. *Environmental Challenges* 2. <https://doi.org/10.1016/j.envc.2020.100012>
12. Kabasiita JK, Malinga GM, Odongo JCW, Opolot E (2021) Factors influencing utilization of municipal solid waste compost among urban farmers in western Uganda. *CABI Agriculture and Bioscience* 2(1): 1–10. <https://doi.org/10.1186/s43170-021-00067-2>
13. Kamoga G, Ssekyewa C (2021) Waste Management Systems among Smallholder Farmers in Masaka and Lyantonde Districts, Central Uganda. *Journal of Agricultural Chemistry and Environment* 10(03): 314–326. <https://doi.org/10.4236/jacen.2021.103020>
14. NAADS (National Agricultural Advisory Services), "Kayunga pineapple factory pre-tested, ready for operation." [Online]. Available: <https://naads.or.ug/kayunga-pineapple-factory-pre-tested-ready-for-operation/> [Accessed: 15 Apr 2022]
15. Abondio RB, Komakech AJ, Kambugu RK, Kiggundu N, Wanyama J, Zziwa A, Kyamanywa S (2020) Assessment of Municipal Organic Solid Waste, as a Potential Feedstock for Briquette Production in Kampala, Uganda. *Journal of Sustainable Bioenergy Systems* 10(2): 62–75. <https://doi.org/10.4236/jsbs.2020.102006>
16. Katimbo A, Kiggundu N, Kizito S, Kivumbi HB, Tumutegyereize P (2014) Potential of densification of mango waste and effect of binders on produced briquettes. *Agricultural Engineering International: CIGR Journal* 16(4): 146–155.
17. Balirwa J, Wanda F, "Impacts of water quality change on beneficial uses of Lake Victoria, Uganda" 2005. [Online]. Available: <https://www.mwe.go.ug/sites/default/files/library/Chapter%2012%20Impacts%20on%20beneficial%20uses.pdf> [Accessed: 30 Mar 2022]
18. Wanda FM, Namukose M, Matuha M (2015) Water hyacinth hotspots in the Ugandan waters of Lake Victoria in 1994–2012: implications for management. *African Journal of Aquatic Science*, 40(1): 101–106. <https://doi.org/10.2989/16085914.2014.997181>
19. Rezanja S, Fadhil M, Fatimah S (2016) Evaluation of water hyacinth (*Eichhornia crassipes*) as a potential raw material source for briquette production. *Energy* 111: 768–773. <https://doi.org/10.1016/j.energy.2016.06.026>
20. Kyayesimira J, Muheirwe F (2021) Health concerns and use of biomass energy in households: voices of women from rural communities in Western Uganda. *Energy, Sustainability and Society* 11(42): 1–13. <https://doi.org/10.1186/s13705-021-00316-2>
21. Mahto P, Dubey V, Panhotra J (2015) Indoor Air Pollution: Health Hazards and Techniques To Reduce the Hazardous Effects. *International Journal of Research* 3(9SE): 1–5. <https://doi.org/10.29121/granthaalayah.v3.i9se.2015.3155>
22. Nsamba HK, Ssali R, Ssali SN, Matovu F, Wasswa J, Balimuni HK (2021) Evaluation of the Cooking Cultures and Practices in Rural Uganda. *Journal of Sustainable Bioenergy Systems* 11(1): 33–44. <https://doi.org/10.4236/jsbs.2021.111003>
23. Amer M, Elwardany A (2020) Biomass Carbonization. In Al Qubeissi M, El-kharouf A, Soyhan HS (Eds.), *Renewable Energy - Resources, Challenges and Applications*. <https://doi.org/10.5772/intechopen.90480>
24. Eltra Elemental Analyzers, "TGA ELTRA Thermostep Thermogravimetric Analyzer: Instruction manual" [Online]. Available: https://www.eltra.com/dltmp/www/53e4b56a-4790-4469-9a6a-636500000000-4eddac3ac644/brochure_TGA_en.pdf [Accessed: 9 Nov 2021]
25. FAO, "Simple technologies for charcoal making," 1983. Vol.41. Rome. [Online]: Available: <http://www.fao.org/docrep/x5328e/x5328e00.HTM> [Accessed: 9 Nov 2021]
26. Liu Z, Jiang Z, Cai Z, Fei B, Yan Yu, Liu X (2013) Effects of carbonization conditions on properties of bamboo pellets. *Renewable Energy* J 51: 1–6. <https://doi.org/10.1016/j.renene.2012.07.034>
27. Fernández RG, García CP, Lavín AG, Heras JL, B. de las, Pis JJ (2013) Influence of physical properties of solid biomass fuels on the design and cost of storage installations. *Waste Management J* 33(5): 1151–1157. <https://doi.org/10.1016/j.wasman.2013.01.033>
28. Singh RN (2004) Equilibrium moisture content of biomass briquettes. *Biomass and Bioenergy* 26(3): 251–253. [https://doi.org/10.1016/S0961-9534\(03\)00082-5](https://doi.org/10.1016/S0961-9534(03)00082-5)
29. de Oliveira Maia BG, de Oliveira APN, de Oliveira TMN, Marangoni C, Souza O, Sellin N (2018) Characterization and production of banana crop and rice processing waste briquettes. *Environmental Progress and Sustainable Energy*, 37(4): 1266–1273.
30. Choudhury HA, Chakma S, Moholkara VS (2015) Biomass Gasification Integrated Fischer-Tropsch Synthesis: Perspectives, Opportunities and Challenges. In Pandey A, Stöcker M, Bhaskar T, Sukumaran RK (Eds.), *Recent Advances in Thermo-Chemical Conversion of Biomass* (pp. 383–435). Elsevier Inc. <https://doi.org/10.1016/B978-0-444-63289-0.00014-4>
31. Deshannavar UB, Hegde PG, Dhalayat Z, Patil V, Gavvas S (2018) Production and characterization of agro-based briquettes and estimation of calorific value by regression analysis: An energy application. *Materials Science for Energy Technologies*, 1(2): 175–181. <https://doi.org/10.1016/j.mset.2018.07.003>

32. Mythili R, Venkatachalam P (2015) Environmental Effects Product Yield and Characteristics of Char. <https://doi.org/10.1080/15567036.2012.721862>
33. Mopoung S, Udeye V (2017) Characterization and Evaluation of Charcoal Briquettes Using Banana Peel and Banana Bunch Waste for Household Heating. *American Journal of Engineering and Applied Sciences* 10(2): 353–365. <https://doi.org/10.3844/ajeassp.2017.353.365>
34. Yazdani MG, Hamizan M, Shukur MN (2012) Investigation of the fuel value and the environmental impact of selected wood samples gathered from Brunei Darussalam. *Renewable and Sustainable Energy Reviews* 16(7): 4965–4969. <https://doi.org/10.1016/j.rser.2012.04.025>
35. Lubwama M, Yiga VA, Muhairwe F, Kihedu J (2020) Physical and combustion properties of agricultural residue bio-char bio-composite briquettes as sustainable domestic energy sources. *Renewable Energy* 148: 1002–1016. <https://doi.org/10.1016/j.renene.2019.10.085>
36. Amarasekara A, Tanzim FS, Asmatulu E (2017) Briquetting and carbonization of naturally grown algae biomass for low-cost fuel and activated carbon production. *Fuel* 208: 612–617. <https://doi.org/10.1016/j.fuel.2017.07.034>
37. Bartocci P, Bidini G, Asdrubali F, Beatrice C, Frusteri F, Fantozzi F (2018) Batch pyrolysis of pellet made of biomass and crude glycerol: Mass and energy balances. *Renewable Energy* 124: 172–179. <https://doi.org/10.1016/j.renene.2017.06.049>
38. Okia DO, Ndiema CK, Ahmed MS (2016) Physical and Chemical Properties of Water Hyacinth Based Composite Briquettes. *Scientific Research Journal IV(Xi)*: 28–36.
39. Tumutegyereize P, Mugenyi R, Ketlogetswe C, Gandure J (2016) A comparative performance analysis of carbonized briquettes and charcoal fuels in Kampala-urban, Uganda. *Energy for Sustainable Development* 31: 91–96. <https://doi.org/10.1016/j.esd.2016.01.001>

Figures

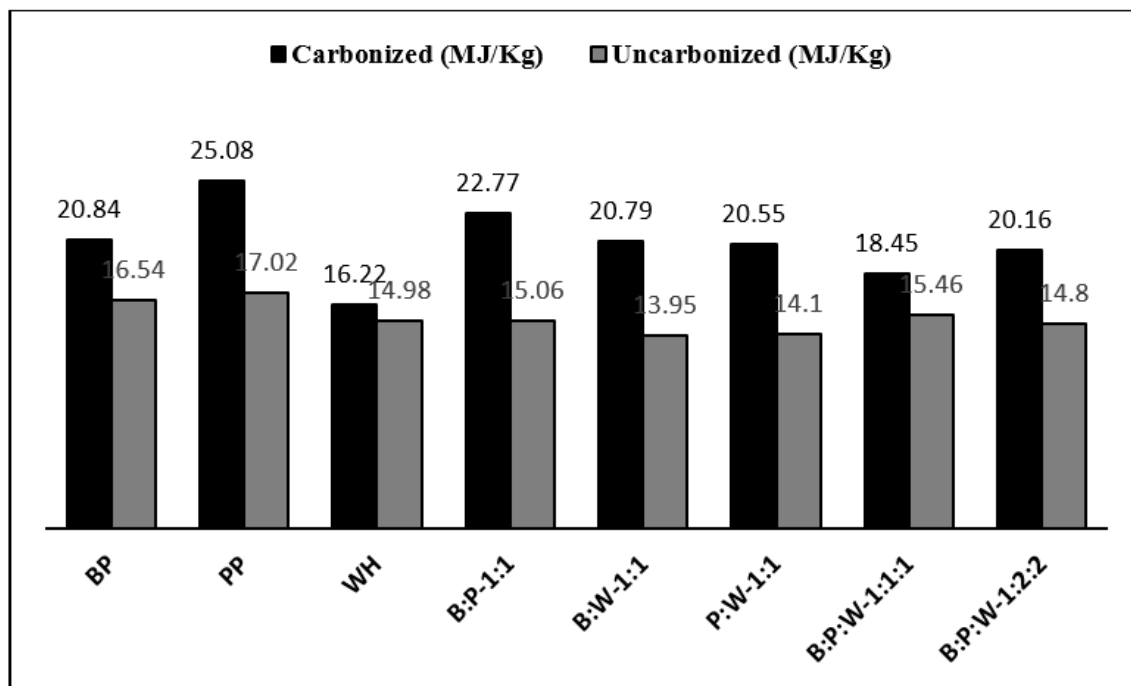


Figure 1

Calorific values for carbonized and uncarbonized briquette samples

Figure 2

Boiling time (minutes) for carbonized and uncarbonized briquette samples

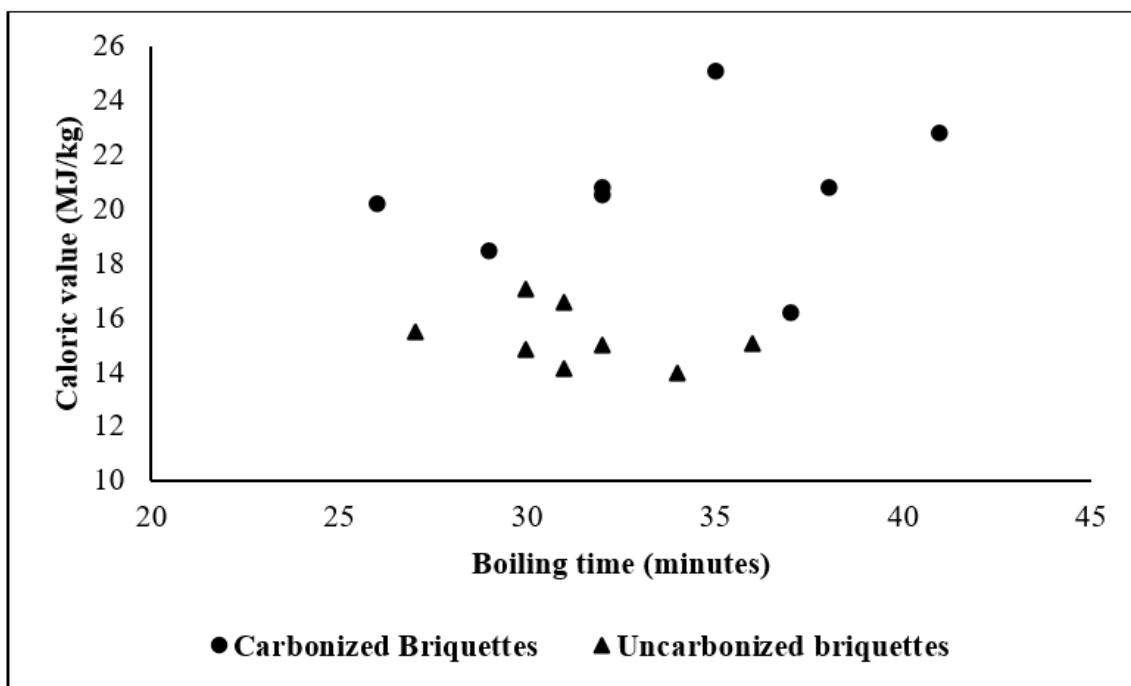


Figure 3

Calorific value versus Boiling time for carbonized and uncarbonized briquettes