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Original Article

Evaluation of Agricultural Waste-Based Briquettes as an Alternative Biomass Fuel for Cooking in Uganda

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ABSTRACT

Wood fuel has been adopted as a feasible alternative to cooking energy sources in efforts to replace fossil fuels. However, the exorbitant use of wood fuel has raised concern as it is the major cause of forest cover loss in Uganda. Briquettes have been recommended as sources of cooking energy with potential to substitute wood fuel. Unfortunately, sawdust, a product of deforestation, is the primary material used in making briquettes in Uganda. This instead augments the problem of fuel-induced deforestation. Agricultural wastes could potentially be converted into briquetting materials for generation of cooking energy, although these are less studied in Uganda. Thus, this study established the potential of agricultural wastes as alternative briquetting materials for use in cooking. Four fuel types: charcoal from Mangifera indica, firewood of Eucalyptus grandis, carbonized and non-carbonized briquettes from agricultural wastes, all from within Mukono District were used for the study. Laboratory based experiments were used to determine the physico-chemical characteristics of the fuels. Data were analysed using R software, Ver. 4.2.3. Carbonised briquettes' mean performance measures were higher than conventional fuels ($p \leq 0.05$) and non-carbonised briquettes. The amount of energy required to attain experimental boiling point of water was higher ($p \leq 0.05$) in conventional fuels and non-carbonised briquettes than in carbonised briquettes. Duration to boil 5 litres of water was least with the conventional fuel sources. All the fuel sources' emissions exceeded the maximum range recommended for indoor carbon monoxide levels. However, the particulate matter emission was lower in carbonised briquettes and charcoal than the other fuel sources. Agricultural waste-based carbonised briquettes could effectively be used as an alternative cooking energy source in Uganda. The study recommends conducting cost-benefit analyses on the use of agricultural waste-based briquettes as cooking energy sources.

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INTRODUCTION

The utilisation of alternative renewable sources of energy to replace fossil fuels has been increasing g in the recent past (Bogdanov, *et al.*, 2019). Consequently, biomass has featured as the most feasible and sustainable alternative source of energy with potential to substitute fossil fuels which are the leading cause of climate change globally (Stuart-Smith *et al.*, 2021; WBA, 2020). This is especially important in the face of increasing global climate change concerns (Sertoli *et al.*, 2022), calling for immediate action to completely eliminate fossil fuels from within the global energy system (WBA, 2020).

To this effect, almost half of the global population and over 80% of Africa’s households are currently using traditional biomass, particularly firewood and charcoal, a cooking fuel source (FAO, 2019; Sola *et al.*, 2017). This evidences the increased importance of biomass as a cooking energy source in most communities of Africa and the entire developing world (Ahmad *et al.*, 2022; Kyayesimira *et al.*, 2021). Most of the biomass used to produce energy for cooking is obtained from forest trees which is then dried to produce quality firewood, or burnt into charcoal (Langbein *et al.*, 2017). Unfortunately, the exorbitant use of forest wood fuel sources is an environmental hazard. This is because the persistent loss of forest cover is also a predisposing factor to the global warming phenomenon and the resultant consequences (Stuart-Smith *et al.*, 2021; Okurut, 2020). Thus, Stuart-Smith *et al.* (2021) did conclude that deforestation is the second after fossil fuels in influencing climate change.

The indiscriminate encroachment on forest resources for wood fuel might deplete forests in the nearby future (Sola *et al.*, 2017). In Uganda, harvesting wood for fuel has been reported as the most threatening cause of deforestation (Bamwesigye *et al.*, 2020). And, the negative consequences of the practice have started showing up, for example, through the fragile climate conditions characterised by frequent droughts and floods in some parts of the country (Okurut, 2020). In addition, utilisation of conventional wood fuel for cooking predisposes the users to risks of contracting respiratory infections stemming from repeated exposure to smoke (Idowu *et al.*, 2023*;* Woolley *et al.*, 2020). Thus, using wood fuel energy sources for cooking is beyond an environmental issue alone, but also a public health concern.

Conversely, briquettes have been applauded as environmentally friendly option to wood fuel as an energy source (Otieno *et al.*, 2022; Mguni *et al.*, 2020; Ali *et al.*, 2019; Hassan *et al.*, 2017). Briquettes also produce fewer toxic emissions into the environment and present less health hazard to humans than conventional energy sources of firewood and charcoal (Pilusa *et al.*, 2013). Furthermore, briquettes have a longer burning time than the convention wood fuel sources, making them more cost-effective to use in cooking (Brenda *et al.*, 2017). Fortunately, briquettes have a ready market and high acceptability, especially in urban communities of

Uganda (EBAFOSA, 2021). More so, briquettes can be applied in a wide variety of settings (Kpalo *et al* 2020), making them appropriate and sustainable even in resource-constrained households. The commonest material used in briquette production in Uganda is sawdust, a forest industry product (Mahoro *et al.,* 2022; Brenda *et al.,* 2017). The use of sawdust-based briquettes is, thus, not in any way a means of reducing the environmental impact of wood fuel-induced deforestation.

More research into other potential forms of biomass that could replace wood fuel for cooking energy generation has spotted agricultural wastes (Ahmad *et al.,* 2022). Fortunately, there is an abundance of agricultural wastes in Uganda and these have been reported as a potential reliable cooking energy source, which, if embraced could act as a means of saving the forest resources (Mugabi & Kisakye, 2021). However, these wastes are under-utilized, yet they would probably reduce the burden on forest resources due to harvesting of wood for fuel. The disadvantage of using agricultural wastes, particularly the crop residues as cooking energy, is that they are loose biomass and burn faster (Tucho & Nonhebel, 2015). Thus, they cannot sustain long cooking operations.

On the other hand, Uganda has not fully explored the potential of using agricultural wastes as a raw material for making briquettes. Furthermore, the quality attributes of briquettes made from the common agricultural wastes in Uganda's cropping systems are also understudied However, is most likely that briquetting these loose materials could enhance their utilisation as a source of energy for cooking. This information would be necessary in efforts to reduce wood fuel-induced deforestation, and also the dependence on sawdust, as the commonly used briquetting material, yet it is also a product of the forest industry. This study established the effectiveness of carbonized and non-carbonized briquettes made using a mixture of agricultural wastes from crop fields, in comparison to the conventional wood fuel energy sources of firewood and charcoal. Unearthing the potential of using agricultural waste-based briquettes as an energy source for cooking is particularly important in addressing the demand for cooking energy sources in the face of increasing population. These wastes, if optimised for cooking would, thus reduce the pressure on the country's forest resources. The findings of this study are crucial in informing policy makers and other players in the energy system on sustainable cooking energy alternatives to forest resources.

MATERIALS AND METHODS

Study Area

The study was conducted in Mukono Municipality. Before the laboratory analyses, a preliminary survey was conducted among 382 respondents randomly selected from Mukono Central Division. The results of the National housing census 2014 revealed that there were 8,333 households in Mukono Central Division. From this number of households, the sample size was determined using the formula by Yamane (1967) as below:

$$n = \frac{N}{1+N(e)^2} \qquad (1)$$

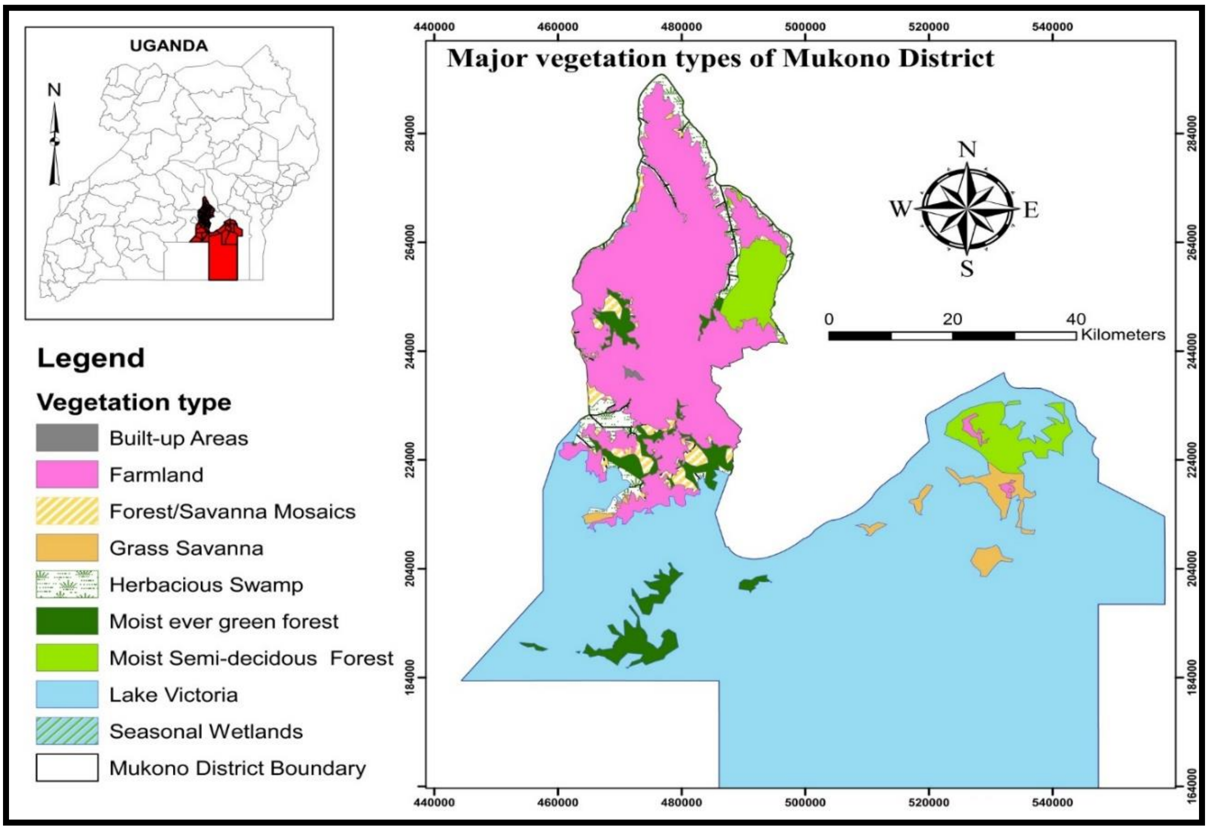
Where **n**= sample size; **N**= population size; **e** = desired level of precision. For this research, ***e*** was 5%

The survey was conducted to assess the level of awareness and use of briquettes for cooking among the urban dwellers. Mukono District is largely surrounded by the waters of Lake Victoria with the remaining land being either forested or farmland. Thus, the place largely depends on forests to obtain fuel for cooking. The study was conducted using a short semi-structured questionnaire administered in face-to-face interviews. The questionnaire sought to obtain data on the fuel sources used for cooking and level of awareness about briquettes within the area.

Source of Materials for the Study

The materials used were obtained from crop fields in Mukono District, the third most populated district in the country. Within Mukono District, the use of firewood and/or charcoal is only tolerated due to the lack of alternative, efficient sources of cooking energy (EBAFOSA, 2021). Thus, briquettes might find a ready market in this district. Furthermore, the biggest part of the district is covered with farmland (Figure 1), indicating potential sustainability in the supply of agricultural wastes for use in making briquettes.

Figure 1: Map of Mukono district with major vegetation types and land uses.



Fuel Materials Used for the Study

The fuel types used in this study were, firewood from *Eucalyptus* wood species, charcoal made from *Mangifera indica* tree species and briquettes made from agricultural wastes- both carbonized and non-carbonised.

Biomass Fuels Sampling

Firewood samples of *Eucalyptus ssp.* with estimated average age of about 9 years were obtained from Uganda Christian University-Mukono campus kitchen storage. These were chopped into sizeable pieces convenient enough to be used in the analyses during the study. The wood pieces used in the study were randomly selected from the available firewood heap.

The Charcoal Production Process

Charcoal was produced from mango branches based on the traditional slow pyrolysis process in traditional kilns used by the local charcoal making communities all over the country. The branches of *Mangifera indica* tree species were cut from a mature mango tree estimated to be around 20 years old. The branches were piled in an orderly manner while ensuring as minimal spaces in-between the pieces as possible (as per the local practice of charcoal making) to allow for complete burning. With many spaces in the pile, the locals, out of the experience, realised that the wood would instead burn to ash and not form charcoal. Thus, the study adhered to this principle. The pile was then covered with grass followed by soil, leaving only one sizeable opening for setting the wood on fire (Figure 2). After the wood was set ablaze, the opening was also covered with soil to minimise entry of oxygen which would interfere with the charring of wood into good quality charcoal. Upon closing the whole pile, controlled openings were created on top of the kiln to keep the fire from dying out before all the firewood charred into charcoal. The kiln was left to char completely until all the wood was burnt into charcoal. This took about five days, after which it was opened. A completely burnt kiln is locally detected by reduced smoke emission and the whole kiln being sunk. This method was adopted for this study. Upon realisation that the kiln had completely burnt, the charcoal was collected while extinguishing the remaining fire with sand. This charcoal making technology is the most commonly used method in all charcoal burning communities of Uganda. It is an almost no-cost technology, except if the wood for making the charcoal is purchased.

Figure 2: Charcoal making process during the experiment

Briquettes Making Technology

Carbonized briquette samples were obtained from Mukono Appropriate Technology Centre (ATC) while the non-carbonized briquette samples were obtained from Jellitone Suppliers Limited. The two companies were contracted to produce briquettes (carbonised or non-carbonised, respectively) from agricultural wastes, particularly for use in the study. The wastes used were a mixture of *Zea mays* cobs, groundnut husks augmented with a mixture of leaves of *Terminalia catapa, Senna spectabilis and Maesopsis eminii*. Both companies adopted the similar briquetting method as per the study requirements as described below, with the difference accruing from the carbonisation process:

The sun-dried materials for the carbonized briquettes were first carbonized before being crushed, while the materials for the non-carbonized briquettes were fed directly into the crusher. The materials were then crushed into sizeable particles for easy mixing with cassava flour solution which was used as the binder. Mixing was done in a mixer, and the admixed composite was then added to a compressor, where the extra water was squeezed out, and the required shapes of the briquettes were obtained (Figure 3). The briquettes were dried under shade on drying racks for a day and were then transferred to dry under the sunshine for three days to allow for complete drying. All the equipment used in the briquette production process were locally fabricated.

Figure 3: L-R- Carbonizer; Residue crashing machine; Mixer; Compressor and Drying racks used for the study

Data Collection

Data collection was through laboratory experiments following the Water Boiling Test (WBT) protocol version 4.2.3 (GACC, 2014) that was used to simultaneously determine emissions levels and combustion properties (Gross calorific values, fuel/energy to cook and time to boil). A

6400 Automatic Isoperibol Calorimeter was used to determine the amount of heat energy available in the fuels by burning a small sample of fuel. The test sample was made to burn completely in a bomb which was pressurized with pure oxygen so that the heat developed by the combustion is absorbed by a definite mass of water. This caused a measurable rise in the water temperature, from which it was possible to calculate the calorific value. The moisture content was determined by heating the samples in a furnace at 105^0C. The moisture content was then calculated as:

$$Moisture\ content\ (\%) = \frac{Wi-Wf}{Wi} * 100 \qquad (2)$$

Where; Wi is the Initial weight of sample and W_f is the Final (dried) weight.

The emissions test was done simultaneously with the water boiling test at Centre for Research in Energy and Energy Conservation (CREEC); Regional Knowledge and Transfer Centre (RKTC) laboratory, Makerere University while the Gross calorific value and moisture content tests were performed at Nyabyeya Forestry College, Masindi District. Laboratory Emissions Monitoring System –LEMS (Figure 4) was used to measure levels of emissions and indoor emissions of carbon monoxide (CO) produced while the fuels were being used to cook. A gravimetric system (Figure 4) was used to determine the mass of PM 2.5 micrometres emitted from fuels. All the experiments investigated physical and chemical properties of the agricultural waste-based briquette samples against the conventional sources of firewood and charcoal.

Figure 4: Left- Set up of LEM; R- Particulate matter emissions reading during WBT experiment

Data Analysis

Data on the level of awareness and use of briquettes for cooking in Mukono Central Division were analysed using descriptive statistics. While data on the physico-chemical attributes of the different fuel types were summarised in Excel spread sheet (version 2016) and imported to R software, Ver. 4.2.3 (R Core Team, 2023). The data were then analysed using analysis of variance (ANOVA) and the means were separated using the least significant difference (LSD) at 5% level of significance.

RESULTS

Level of Use of Different Fuel Sources and Awareness about Briquettes

The findings of the preliminary survey are reported in *Table 1* below. Most (over 90%) of the respondents were females and primarily used either charcoal (79.3%) or firewood (12.7%) for cooking. None of the respondents used briquettes for cooking and most (47.3%) had never heard of briquettes.

Table 1: Usage of different fuel sources and level of awareness about briquettes

Variable	Attributes	Frequency (N=382)	Percentage
Gender	Female	352	92.1
	Male	30	7.9
Fuel sources	Firewood	49	12.7
	Charcoal	303	79.3
	Paraffin/ Kerosene	13	3.3
	Electricity	2	0.6
	Gas	15	4
	Briquettes	00	00
	Biogas	00	00
Level of awareness about briquettes	Yes	155	40.7
	No	181	47.3
	Not sure	46	12

Heating Value and Moisture Content

The heating (Calorific) values and moisture content of the different fuel types are presented in *Table 2*. Charcoal had higher ($p \leq 0.05$) calorific value than all the other energy sources while carbonised briquettes had the least ($p \leq 0.05$) calorific value. No difference in calorific value was realised between firewood and non-carbonised briquettes. The moisture content also varied among the different energy sources. Charcoal had the least ($p \leq 0.05$) moisture content followed by the carbonised briquettes, while no difference ($p \geq 0.05$) was realised between firewood and non-carbonised briquettes.

Table 2: Calorific value and moisture content of the different energy sources

Fuel	Calorific value (MJ/kg)	Moisture content Wet basis (%)
Charcoal	29.70^{a}	6.27^{c}
Firewood	17.57^{b}	12.23^{a}
Carbonized briquettes	16.23^{c}	8.10^{b}
Non-carbonized briquettes	17.50^{b}	11.67^{a}
SEM	0.48	0.25
LSD	1.12	0.58
p-Value	0.00	0.00

Values with different superscripts within a column are statistically significant at 5% level of significance; SEM = Standard Error of the Means

Fuel Emissions and Other Combustion Properties of the Different Energy Sources

From the combustion experiment, it required lower ($p \leq 0.05$) amounts of either charcoal or carbonised fuel to cook 5 litres of water to boiling point than did firewood or the non-carbonised briquettes (*Table 3*). Charcoal emitted the highest ($p \leq 0.05$) amount of carbon monoxide (CO) while the briquettes emitted the least. The emission of particulate matter (PM2.5) was the least from carbonised briquettes and charcoal, while the least energy required to cook the 5L of water was when carbonised briquettes were used. Firewood cooked the 5 litres of water faster than any other fuel while, using carbonised briquettes took the longest time to boil the same amount of water.

Table 3: Emissions and other combustion properties of different energy sources

Performance measure	Fuel				SEM	LSD	p-Value
	Charcoal	Firewood	Ca_B	Non-Ca_B			
Fuel to cook 5L (g)	175.67^{b}	563.00^{a}	175.4^{b}	550.37^{a}	16.11	37.15	0.00
CO to Cook 5L (ppm)	78.9^{a}	70.3^{ab}	50.47^{bc}	36.73^{c}	9.63	22.21	0.01
PM to Cook 5L (mg)	514.77^{b}	3177.87^{a}	348.53^{b}	3247.47^{a}	764.3	1762.42	0.01
Energy to Cook 5L (kj)	5010.00^{b}	9150.00^{a}	2633.33^{c}	8897.67^{a}	260.9	601.61	0.00
Time to Boil (min)	28.87^{b}	16.70^{c}	49.30^{a}	32.93^{b}	2.45	5.65	0.00

Values with different superscripts within a row are statistically significant at 5% level of significance; SEM = Standard Error of the Means; Ca_B = Carbonized briquettes; Non-Ca_B = non-carbonized briquettes; PM =Particulate matter; CO = Carbon monoxide

DISCUSSION

Level of Use of Different Fuel Sources and Awareness about Briquettes

Results from the preliminary survey revealed a high involvement of females in fuel-related issues due to their high participation in the study. This is probably because, in most Ugandan communities, the females are responsible for cooking and sourcing the energy source to use in cooking. In agreement to the current findings, Mahoro *et al.*, (2022) also reported high participation of women in a study assessing the level of adoption of briquette use.

The fact that none of the respondents was using briquettes for cooking is similar to findings by Mahoro *et al.*, (2022) who also reported low usage of briquettes for cooking in Kampala. The low use of firewood as (12.7%) opposed to the 79.3% respondents using charcoal quite contradicts with a nationwide report by Katutsi *et al.* (2020) who reported higher utilisation of firewood for cooking. However, this could be because the study was conducted in the urban part of the district, yet Katutsi *et al.* (2020)'s report gives a country overview, including the rural households. More often, there are more charcoal sellers in the urban centres than there are firewood sellers. Thus, access to charcoal is easier than access to firewood. This could explain the high use of charcoal than firewood.

It is quite unfortunate that this study did not seek to explain which factors drove the respondents to use either firewood or charcoal and not briquettes. However, a study by Mainimo *et al.* (2022) in Wakiso District revealed that price, household income, gender of household head, household size, and most importantly, restriction on fuel use did influence the choice of a fuel. Since there is laxity on implementing restrictions regarding deforestation for fuel in Uganda, it could be the reason for continual use of wood fuel for cooking, despite the potential deleterious environmental effects. Thus, sensitisation on the importance of briquettes, particularly the agricultural waste-briquettes, should be done to save the forest cover.

Although most of the respondents were unaware of briquettes as a potential cooking energy source, the knowledge of the problem accruing from using charcoal and firewood is evident (EBAFOSA, 2021; Ali *et al.*, 2019). Consequently, with increasing sensitisation campaigns, adopting agricultural waste-based briquettes as an alternative cooking energy source could meet with ready acceptance.

Physico-Chemical Properties of Different Fuel Types

From the current study, charcoal had the highest calorific value than all the other fuel types. During the thermo-chemical processing of wood to make charcoal, most of the moisture and volatile matter are expelled as a result of the slow pyrolysis process (Lubwama *et al.*, 2021). This gives charcoal a higher calorific value and low moisture content. Although the calorific value of charcoal is also dependent on tree species from which it was obtained, the current study has realised ignoble deviations from earlier studies as a result of tree species used. For example, in examining charcoal from *Dichrostachys cinerea, Morus Lactea, Piliostigma thonningii, Combretum mole, Albizia grandibracteata*, Lubwama *et al.* (2021) reported calorific values of 28.10 MJ/kg, 28.61 MJ/kg, 28.99 MJ/kg, 28.88 MJ/kg and 28.35 MJ/kg, respectively. The findings from the above study are quite comparable to the 29.70 MJ/kg caloric value of *Mangifera indica* charcoal from the current study.

The low calorific value of the carbonized briquettes deviates from the findings by Ju *et al.* (2020) and Deshannavar *et al.* (2018) who reported higher values of carbonised biomass compared to the respective wood from which the materials were obtained. The low calorific value in the current study could be because the briquettes constituted of a mix of residues, hence the elimination of volatile matter could not have been uniform. Nevertheless, the calorific value of the carbonised briquettes is comparable to that reported by Nazari *et al.* (2019). In addition, the higher calorific values (heating effect) of the charcoal, firewood and non-carbonised briquettes suggest that they burn quickly and directly and thus do not last long while carbonised briquettes burn slower but more persistently.

Fortunately, the moisture content of the carbonised briquettes in the current study was lower than for firewood and the non-carbonised briquettes, but comparable to that of charcoal. Low moisture content is critical of a good-quality briquette (Anggraeni *et al.,* 2021; Ajimotokan *et al.,* 2019). The moisture content of the briquette affects the combustion process since, with high moisture content, the heat produced will evaporate the water first (Suryaningsih *et al.*, 2018). With regards to the moisture content of charcoal, there is agreement with Zichen *et al.* (2017) who demonstrated effectiveness of charcoal-making technology in disposable moisture reduction. Conversely, the moisture content of carbonised briquettes made from charcoal particles of was lower (about 6.5%) (Ajimotokan *et al.,* 2019), compared to the 8.1% obtained in the current study. This could be attributed to the moisture reduction during the charcoal making process, unlike in the current study where the agricultural wastes were not first turned to charcoal. The calorific value and moisture content of both firewood and non-carbonized briquettes did not differ ($p \geq 0.05$). It must be pointed out that this study's moisture content and calorific energy value comparisons are based on a relatively narrow range of variables. Other variables such as cook stove efficiency and technology used in making briquettes could have also been influential factors, and should thus be studied.

Equal charcoal and carbonised briquettes were required to boil 5 litres of water. At shorter cooking times, both fuel sources perform equally (Brenda *et al.*, 2017). The reduced amount of briquette required to boil 5 litres of water corresponds to earlier reports, for example, by Yahaya and Ibrahim (2012).

The results on carbon monoxide levels during cooking revealed higher emissions from conventional fuel sources; the highest was from charcoal. This makes briquettes more environmentally friendly and has minimal health risks for the user. These findings agree with Akolgo *et al.* (2021) who realised similar comparative advantage of briquettes to conventional cooking energy sources with regards to carbon monoxide emissions. Previous studies (Xiu *et al.,* 2018; Fachinger *et al.,* 2017) indicate that the emissions are subject to type of raw materials (biomass) used, type of wood fuel burnt and the level of carbonization. Incompletely burnt wood tend to produce more emissions than the fully charred charcoal. However, the ranges of carbon monoxide from the different fuels used in the current study exceeded the 9ppm and 10-24ppm range for maximum recommended indoor levels. These ranges expose one to possible health effects with long term exposure (ASHRAE, 2018). While ASHRAE (2018) lists maximum allowable short-term limit of 9ppm the Environmental Protection Agency (EPA) has set two national health protection standards for Carbon monoxide: a one-hour Time Weighted Average (TWA) of 35 ppm, and an eight-hour

TWA of 9ppm. These standards make it clear that any carbon monoxide reading over 9ppm should be investigated and acted upon.

Particulate matter emission by either charcoal or carbonised briquettes was lower than for firewood and non-carbonised briquettes. The results show that use of carbonised briquettes offers a better option to combat particulate matter ($PM_{2.5}$) emissions responsible for indoor air pollution. Particulate matter emissions are of a great public health concern, globally predisposing, especially, many infants to premature death (Anderson *et al.*, 2012). High levels of particulate matter emissions from use of firewood (Gioda *et al.*, 2019) have raised the campaign to establish alternative cooking energy sources. With the current low PM emission from carbonised biomass briquettes, it could be evident that the health risk could be reduced if the use of agricultural waste-based briquettes is adopted. The findings in the current study are in congruence with Kipngetich *et al.* (2023); Morales-Máximo *et al.*, (2022) and Sun *et al.* (2019) who appraised briquetting as a practical means of reducing the effect of $PM_{2.5}$ emissions on human health due to use of firewood for cooking.

Firewood had the shortest (16.70 minutes) boiling time while carbonised briquettes registered the longest time (49.30 minutes) to boil 5 litres of water. As was also reported by Davies *et al.* (2013), having a high calorific value doesn't guarantee a shorter boiling time. The shorter boiling time for firewood could also be a factor of the faster energy release of the firewood, unlike the carbonised briquettes which are characterised by slow energy release but longer burning time. This is evidenced in the low energy requirement from carbonised briquettes to boil the 5 litres of water.

CONCLUSION

Charcoal is the study area's most used cooking energy source, and none of the respondents used briquettes. In addition, the level of awareness of the same was still low. Generally, carbonised briquettes made from agricultural wastes proved superior to Uganda's conventional cooking energy sources. In addition, the low particulate matter and carbon monoxide emission from the carbonised briquettes revealed a reduced health risk from using agricultural waste-based briquettes in cooking. Although the conventional cooking energy sources had higher calorific values, low amounts of the carbonised briquettes were required to boil 5 litres of water. Equally, a lower amount of energy from briquettes was required to boil the same amount of water. Consequently, agricultural can substitute the commonly used briquetting materials, the saw dust, to save Uganda's forest cover. However, a cost-benefit analysis for the use of agricultural waste-based briquettes will be conducted in comparison with other conventional wood fuels and sawdust-based briquettes. Mass sensitisation campaigns on the importance of using agricultural waste-based briquettes for cooking could be necessary in ensuring their adoption.

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Data Availability

All the necessary data for this study is availed within the paper.

Authors' Contributions

All authors confirm their contribution to the paper as follows: study conception and design: Oteu OJ, Kizza-Nkambwe S, Angunyo MF; data collection: Oteu OJ; analysis and interpretation of results: Kasima JS; draft manuscript preparation: Oteu OJ, Kizza-Nkambwe S, Kasima JS, Mpewo M. All authors agree to the content of the final version of the manuscript.

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