

Assessment of Municipal Organic Solid Waste, as a Potential Feedstock for Briquette Production in Kampala, Uganda

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Abstract

The current shortage of energy resources coupled with environmental degradation problems resulting from deforestation in Uganda has contributed to increased demand for renewable energy resources including municipal organic solid waste and agricultural residues. However, organic waste from Municipal Solid Waste (MSW) may contain contaminants that are harmful to public health and the environment. This study determined the heavy metal concentration in MSW in Kampala City, Uganda. Also, the physicochemical properties of briquettes produced from the MSW were compared with charcoal. The waste samples were collected from residential, institutional and market areas over a period of two weeks. They were then analyzed for the presence of heavy metals. Briquettes were made from the bio-waste and were subjected to calorific and proximate analysis. Results indicated that the mean concentrations of Cd, Cr, Cu, Fe, and Pb were 1.25 mg/kg, 2.04 mg/kg, 38.2 mg/kg, 3.97 mg/kg and 1.99 mg/kg respectively while Hg was not detected. The calorific values of briquettes ranged from 8.9 to 15.3 MJ/kg and were lower than those of charcoal. Heavy metal concentrations in bio-waste collected were below the permissible acceptable limits. These findings indicate that the sampled MSW does not pose a health hazard arising from the presence of such heavy metals and therefore could be a safe source of renewable energy.

Keywords

Organic Waste, Heavy Metal Concentration, Briquettes, Calorific Value, Renewable Energy

1. Introduction

The rapid population growth, urbanization and economic development in many sub-Saharan African countries such as Uganda have increased resource consumption and waste generation [1]. This has led to increased environmental contamination in mainly urban centers. In Uganda, Kampala city is faced with a crisis of municipal solid waste (MSW) management [2] [3] [4]. With a waste generation rate of between 0.5 to 1.2 kg/capita/day [5], an estimated 1000 tons of waste is generated per day. According to [3], over 90% of this waste is organic in nature. However, about 60% of this waste remains uncollected [3] [4] and is dumped in illegal places causing health and environmental problems [2] [3]. [6] observed that this uncontrolled dumping and mismanagement of MSW leads to the accumulation of heavy metals in the environment. However, municipal organic solid waste is a potential energy resource that can alleviate the pressure on conventional biomass sources in meeting the energy demand of Kampala City [7]. According to [3] and [5], over 28,000 tons of potential feedstock are available for energy generation from Kampala's municipal waste per month. Despite this, the concentration level of hazardous heavy metals in this bio-waste is unknown. Thus, it is not known how suitable the organic wastes are for use as a feedstock for briquette production. These hazardous wastes, if present in significant quantities in the MSW, may pose a threat to potential consumers of the briquettes through endangering their health [8] [9]. Therefore, this study investigated the hazardous heavy metal content in municipal organic solid waste of Kampala City. This was done to assess the suitability of such waste as a feedstock for domestic fuel briquette production.

2. Materials and Methods

2.1. Study Area

This study was carried out in Kampala, the capital city of Uganda with a total area of about 189 km² [10]. The estimated population of Kampala is over 1.51 million [11] and is characterized by rapid urbanization, and low standards of living in especially its slums and other informal settlements. Kampala district, which is under the jurisdiction of Kampala Capital City Authority (KCCA), is divided into five divisions. These are: Central; Nakawa; Makindye; Kawempe, and Rubaga.

2.2. Sampling Procedures

Waste samples were randomly picked from residential areas, educational and market places within Kampala city. Makerere and Kyambogo universities were selected to represent the educational institutions while Nakasero and Kalerwe markets represented market places. Residential waste was picked randomly from different households across Kawempe and Nakawa divisions.

At the sampling sites, organic waste components were identified and sorted manually. Thirty-six (36) samples of well-mixed organic waste each weighing 10

kg were randomly collected from the six different places as mentioned previously. Polythene plastic bags used to carry the waste samples, were sealed properly for safe transportation. The experiment was repeated for a period of six days selected from two consecutive weeks *i.e.* three days randomly selected from each week. The collected waste samples were transported to Makerere University Agricultural Research Institute Kabanyolo (MUARIK) for sun drying and briquette production. Sun-drying was done for two weeks. This reduced the moisture content of waste samples to about 15% wb.

2.3. Sample Preparation

2.3.1. Sample Preparation for Heavy Metal Analysis

One kg of each sun-dried organic waste sample was taken to Makerere University, Soil Sciences Laboratory for hazardous heavy metal analysis. The samples were however first placed in an oven where they were dried at 60°C until no change in weight of the samples was noticed, as recommended by [3].

2.3.2. Preparation of Carbonized Briquettes from Waste Samples

The carbonization of organic solid waste was done at MUARIK using slow pyrolysis in a steel batch reactor as described by [12]. The procedure was as follows: 5 kg of sun-dried waste samples were fed into the batch reactor. The reactor was then heated to temperatures ranging from 350°C - 600°C for 180 - 240 min (Variations in temperature and time is due to non-homogeneity of the waste samples). The samples were then removed and crushed into powder using grinding machine (Christy hunt machine with Brook Crompton Series 2000—AC Electric Motor Starters) before being sieved using a sieve of 1.5 mm in size. Adhesives (cassava and molasses which are the commonly used binders) were then mixed with carbonized powder samples (1.5 kg each) in a container. The mixing ratios used were Char:Cassava flour:Water (1.5 kg:0.75 kg:2 L) and Char:Molasses:Water (1.5 kg:750 mL:2 L) [13]. Briquettes were then produced using a hydraulic hand press machine (OMEGA 25 Ton Shop Press Serial No. 40253) before being sun-dried for a week.

2.4. Laboratory Analysis

2.4.1. Heavy Metal Content

The concentration levels of Cd, Cr, Cu, Fe, Hg and Pb in organic waste samples collected from different areas were determined. The laboratory procedure as proposed by [14] was followed in the heavy metal analysis. In the procedure, the dried samples were ground into a powder using a mixer grinder (Geerpas Industries, Model GSB 1624) to yield a representative homogenous sample. One gram of the representative sample, measured using an Electronic Compact Scale (model SF-400C) was put in a digestion tube. Acid mixture reagent [Conc. HNO₃ + Conc HCl (1:3)] of nitric acid and hydrochloric acid (aqua regia) was used for the digestion process. The samples in the digestion tubes were then dried at 80°C. After drying was complete, the resulting solution was removed

from aluminum block digester, and cooled down. It was then diluted with 50 mL distilled water to obtain the metal ions of interest. A standard (Fisher Scientific) was introduced to the digested samples, filled in vials. The concentrations of metal ions [Cd, Cr, Cu, Fe, and Pb] were then determined using Microwave Plasma Atomic Emission Spectrometer (MP-AES) (Agilent Technologies, SPS 4 Autosampler, Model No. G8410A) together with Inductively Coupled Plasma Mass Spectrometry (ICP-MS) (EDX1800B Desktop XRF).

2.4.2. Physico-Chemical Properties of Briquettes

The physicochemical properties of briquettes analyzed included the calorific value, moisture content, volatile matter, ash content and fixed carbon. The procedure followed in their determination is as shown below:

Calorific Value

A C2000 IKA Digital bomb calorimeter was used to determine the heating value of fuel briquette as was specified by [15] as follows: a sample weighing one gram was placed in a crucible inside a bomb calorimeter that had been pressurized with oxygen. The sample was ignited and burned completely. The calorific value was calculated using Equation (1).

$$CV = \left((M_w + M_g) \times (T_2 + T_1) \right) / X \quad (1)$$

where: CV = calorific value (kJ/kg), M_w = mass of water placed in the calorimeter (g), M_g = water-equivalent weight of the apparatus (g), T_1 = initial temperature of water in the calorimeter ($^{\circ}\text{C}$), T_2 = Final temperature of water in the calorimeter ($^{\circ}\text{C}$) and X = Mass of fuel sample taken in the crucible (g).

Moisture Content (Mc)

The procedures as used by [16] were followed in determining the moisture content of briquettes. Equation (2) was then used to calculate its moisture content (dry basis).

$$M_c = \left((W_A - W_d) / W_A \right) \times 100\% \quad (2)$$

where: M_c = Moisture content (%), W_A = Weight of wet briquette in kg, W_d = Weight of oven-dried briquette in kg.

Volatile matter, ash content and fixed carbon

The methodology as followed by [17] was used to determine the volatile matter, fixed carbon and ash content of the biofuel briquettes. The Equations (3)-(5) show how these parameters were calculated.

Volatile Matter (VM) %

The percentage of the volatile matter was calculated using Equation (3).

$$V_m = \left((W_d - W_w) / W_d \right) \times 100\% \quad (3)$$

where: V_m = volatile matter content (%), W_d = weight of dry fuel (g), W_w = weight of fuel after (7) seconds (g).

Approximate Ash Content

Equation (4) was used to determined ash content (%).

$$Ash = (W_{ash} / W_d) \times 100 \quad (4)$$

where, W_{ash} = weight of the ash (kg), W_d = weight of dry fuel (kg).

Fixed Carbon Content %

The fixed carbon was calculated by subtracting the sum of the percentage of moisture content, volatile matter and ash content from 100, Equation (5) was used.

$$FC = 100 - (M_c + V_m + Ash) \quad (5)$$

where, FC = fixed carbon, V_m = volatile matter (%), M_c = Moisture content (%) and Ash = ash content (%).

2.5. Data Analysis

Descriptive statistics for heavy metals concentration and physicochemical characteristics of fuel briquettes were obtained using R software. One-way analysis of variance (ANOVA) tests was used at $p \leq 0.05$ to establish any differences in parameters measured. Where significant differences were detected, the Tukey test was used to further ascertain statistical significance between groups.

3. Results and Discussion

3.1. Heavy Metal Content

Results indicated that different heavy metals were present in organic waste samples except for mercury (Table 1). Cadmium and lead concentration (1.25 and 1.99) mg/kg respectively were present only in organic waste samples collected from educational institutions. The concentrations are below the maximum acceptable limits recommended [14] [17] [18] [19]. Thus, organic waste from the study area is safe enough to be used for bioenergy production. The organic waste from residential areas contained the highest concentration of copper followed by market places (Table 1). However one-way ANOVA showed that there was no significant difference ($p > 0.05$) between the heavy metal content in organic waste from the different places (Table 1).

[6] [20] [21] noted that some heavy metals originate from crops planted around the contaminated wetlands, MSW dumpsites, and water bodies. Also, the uncontrolled disposal of industrial waste in especially the water channels contributed to the presence of heavy metals like Cu, Cd, Fe, Pb, and Cr in the environment [6].

Table 1. Concentration of heavy metals in organic waste collected from dumpsites (n = 6).

| Treatment ^y | Heavy metal concentration levels (mg/kg) | | | | | |
|------------------------|--|-------|-------|-------|-------|-----|
| | Pb | Cr | Cd | Cu | Fe | Hg |
| Residential | 0.00a | 0.12a | 0.00a | 38.2a | 2.67a | 0.0 |
| Market | 0.00a | 0.10a | 0.00a | 31.9a | 1.63a | 0.0 |
| Educational | 1.99a | 2.04a | 1.25a | 30.2a | 3.97a | 0.0 |

y. Means with same letter, columns wise, indicate no significant difference ($p \leq 0.05$) among treatments, n = number replicate per sample.

Therefore responsible governmental bodies must enforce regulations governing the disposal of industrial waste and farming in sensitive urban wetlands. **Table 1** also shows that the educational institutions' organic waste had a relatively higher concentration of the other heavy metals aside from copper compared to the other areas. According to [22], indoor dust generated by the adult population is a possible source of Pb and Cd contamination. It is therefore likely that the larger quantity of dust generated by the higher population in educational institutions could explain the unusually higher content of Pb and Cd found in its waste. [23] carried out a study in Nigeria that reported higher levels of heavy metals in MSW compared to this study. This may be because their study assessed MSW at the landfill and the continuous buildup of heavy metals therein could probably have contributed to high concentrations observed compared to this study.

Organic waste from the different areas contained a higher concentration of copper (**Table 1**). A study by [24] reported a higher concentration of Cu (40.4 mg/kg) in crops around the Lake Victoria basin. Their explanation for this was that the higher concentration of the metals in soil could have led to higher levels in the crops cultivated around the area. The origin of the heavy metals in the soil could be due to poor waste management and lack of appropriate disposal of industrial, agricultural and residential waste in urban places, which are dumped in wetlands and lake Victoria shores [6].

3.2. Physico-Chemical Properties of Briquettes

Calorific Value

Table 2 shows the mean calorific values of the different briquettes and charcoal. Generally charcoal had a higher calorific value ($p < 0.05$) compared to the briquettes produced from organic waste. **Table 2** also shows that the educational institutions' waste briquette had a higher calorific value compared to the briquettes derived from the market and residential organic waste. However, there was no significant difference ($p > 0.05$) between it and the former (**Table 2**). Also, there was no significant difference ($p > 0.05$) between the calorific value of briquettes bound with different binders. According to [3], the organic waste collected from Kampala had a gross energy content of 17.3 MJ/kg a value that is similar to the one obtained in this study.

Table 2. The mean calorific value of cassava binder, molasses binder briquette, and charcoal ($n = 3$).

| Treatment ^y | Calorific value MJ/kg ($n = 3$) | | |
|------------------------|-----------------------------------|---------------|----------|
| | Briq_cassava | Briq_molasses | Charcoal |
| Residential | 8.90a | 9.58a | 28.52a |
| Market | 15.26b | 14.70b | 28.52a |
| Educational | 13.29b | 13.17b | 28.52a |

y. Means with same letter, columns wise, indicate no significant difference ($p \leq 0.05$) among treatments, n = number replicate per sample. Where, Briq_cassava = cassava bound briquette, *Briq_molasses = molasses bound briquette.

The calorific values of bio-waste briquettes produced satisfied what was recommended by [25] for fuel briquettes. A similar study by [16] noted that the gross calorific values (GCV) of rice husk briquettes in Uganda ranged between 12.77 MJ/kg and 14.54 MJ/kg. [26] also found that the calorific values of mango organic waste briquettes ranged between 15.1 MJ/kg and 16.14 MJ/kg, depending on the type of binder used. According to [27], the specific heating density and combustibility of fuel briquette could be upgraded with the addition of between 10% - 20% very fine char items such as charcoal or coal into the briquette. However, the briquettes made of organic waste from educational institutions had higher calorific value compared to the findings by [16] for rice husk and were similar to briquettes from mango organic waste as reported by [26]. Also, briquette from the market waste had a similar calorific value with the findings by [16] for rice husk briquette in Uganda. The better performance of this briquette is maybe due to the mixed types of organic waste generated in education institutions, for instance, paper waste which is a forest by-product, yard waste, and others. Also, a similar finding was reported by [3].

The briquettes produced using cassava and molasses binders had their calorific values varying between 8.90 - 15.26 MJ/kg. However according to [25], a commercial fuel briquette should have a calorific value greater than 17.5 MJ/kg. This implies that organic waste briquette produced cannot be satisfactorily used as an alternative energy source. Also, their heating values were lower than that of fossil fuels like kerosene (46.5 MJ/kg), natural gas (37.3 MJ/kg) and hard coal (31.80 MJ/kg) [28]. Despite this, if they are sorted and more combustible fractions are selected then they have the potential to be an important source of energy. This is because of their sustainability as well as other enormous environmental benefits [29].

3.3. Proximate Analysis of Organic Waste Briquettes

3.3.1. Moisture Content

The average moisture content of charcoal, organic waste briquettes bound with cassava and molasses binders are shown in **Table 3**. Charcoal had the highest moisture content of 8.12% followed by briquettes made from market organic waste with molasses binder of 4.65% and the lowest was observed in briquette made from residential waste bounded with molasses. One-way ANOVA showed that there was a significant difference ($p < 0.05$) between the moisture content briquettes and charcoal. However, there was no significant difference ($p > 0.05$) in moisture content between the different briquettes. According to [30], the low moisture content in briquettes enables proper handling during storage and transportation. The lower moisture content of the briquettes can be attributed to the design and size of molders used to produce briquette. Several studies recommended that quality briquette contains moisture content ranging between 10% to 15% [31] [32] [33]. However, the organic waste briquettes, as well as charcoal, have moisture contents below the recommended value. The briquette made of market waste had the highest moisture content compared to briquettes

from other areas. Also, the study by [26] reported higher moisture content of 11.9% for briquette compared to current study findings. According to [26], the chemical bonded within the materials and binders used had a high effect and some with higher water holding capacity. However, [34] observed a lower moisture content (2.04%) from Buffing Dust (BD) briquettes compared to the current study. Furthermore, [32] noted that the briquette with high moisture content had low bulk densities and became more fragile during handling. Generally, the moisture content of the briquette determines the quality and burning characteristics of that briquette. The briquettes with low moisture content will be easily ignited during burning and higher heating values are expected from the fuel [35]. However, the briquettes with higher moisture content will use much of the heat to evaporate the excess water [36], thus causing a lower burning rate and less heat is generated with too much smoke emitted.

3.3.2. Volatile Matter and Ash Content

The results of the volatile matter in the different fuels are as shown in Table 3. On average the volatile matter from the Briquettes was 25.0% while that of charcoal was 22.0%. However, these differences were not significant ($p > 0.05$). According to [37] charcoal volatile matter varies from a high of at least 40% to a low of 5% or even less. Also, [37] noted that prolonging the carbonization of charcoal at a high temperature produces a fuel with a lower volatile matter. When the carbonization heat is low and the retort time is short, then the volatile content rises.

However, [38] reported that biomass fuel with a combination of higher volatile matter and lower moisture percentage is an indicator of charcoal having a better flammable length and combustion properties. [39] also noted that feedstock with lower volatile content would result in inefficient utilization. [26] also observed that feedstock used to produce briquettes usually determines the value of the volatile matter in fuel.

Several studies have proven that the proportion of volatile matter has a strong effect on the burning behavior of fuels [26] [31] [34] [40]. However, a study by [26] that investigated the mango waste briquette reported lower values of volatile matter than in the current study. Also, [34] [36] also observed lower values of

Table 3. Proximate analysis of briquette bounded with cassava, molasses, and the charcoal ($n = 3$).

| Proximate composition of briquettes and charcoal | | | | | | | | | | | | |
|--|--------------------|---------|--------|-------------------|---------|-------|---------------|---------|-------|------------------------|---------|-------|
| Treatment ^y | Moisture content % | | | Volatile matter % | | | Ash content % | | | Fixed carbon content % | | |
| | Brq_cas | Brq_mol | char | Brq_cas | Brq_mol | char | Brq_cas | Brq_mol | char | Brq_cas | Brq_mol | char |
| Residential | 3.57a | 3.37a | 7.10ab | 21.1a | 26.3a | 22.9a | 55.1a | 54.0b | 5.03a | 20.6a | 16.3a | 64.5a |
| Educational | 3.58a | 4.13b | 5.97a | 23.9a | 30.0a | 19.6a | 41.5a | 36.7a | 5.38a | 30.0a | 28.7c | 69.0a |
| Market | 4.32a | 4.65c | 8.12b | 20.8a | 28.9a | 23.4a | 53.1a | 42.5a | 5.82a | 22.7a | 24.5b | 63.0a |

y, Means with the same letter, columns wise, indicate no significant difference ($p \leq 0.05$) columns wise. Where, *Char = charcoal, *Brq_cas = cassava binder briquette, *Brq_mol = molasses binder briquette, n = number of replicate per sample.

volatile matter in briquettes produced from rice husk and tannery waste than this study's findings. Also, [40] reported that briquette fuel with a higher volatile matter had a better burning efficiency. This was observed in educational and market waste briquettes bound with molasses which had higher volatile matter than briquettes bound with cassava. According to [34], briquettes usually use more energy to burn off the volatile matter in fuel before heat energy is released for the intended purpose. Therefore these briquettes which had comparatively high volatile matter would use more energy to burn off the volatile matter as opposed to charcoal that had a lower volatile matter. Generally, a high percentage of volatile matter is an indicator of low fixed carbon content. However, the recommended values of volatile matter for domestic cooking fuel range between 20% and 30% with the marginal acceptable value of about 40% [41]. Therefore, the organic waste briquettes made with cassava binder and molasses binder were within the recommended value hence showing that these briquettes can be good for domestic use.

3.3.3. Ash Content

The ash content of the different briquettes and charcoal are shown in **Table 3**. The quantity of ash (55.1%) that had remained after the incineration of organic waste briquette bound with cassava binder from residential waste was the greatest followed by the briquettes made with molasses binder (54%) while the lowest was observed in charcoal (5.03%). One-way ANOVA showed that there was a significant difference ($p < 0.05$) in ash content between the different briquettes and charcoal. However, there was no significant difference ($p > 0.05$) in the ash content of the different briquettes. Similar studies by [26] [42] [43] reported lower percentage ash content in briquettes than the current finding. However, [42] noted that feedstocks types and binders used could have had a great effect on the ash content of the briquettes.

[44] [45] reported that low ash content of briquette was an indicator of a high calorific value of a fuel. Also, [42] [46] observed that the higher the ash content of the feedstock, the lower the burning rate as well as the heating value of the fuel. Furthermore, the higher ash content may cause problems in handling and disposal or during the cooking time because the ash may block the air holes and eventually lower the oxygen supply in the combustion chamber of the cooking stove [47]. Several studies recommend that the ash content should be 3% to 4% for good quality briquettes [48] [49]. In this regard, the briquettes produced may not qualify to be very desirable.

[50] however noted that the construction industry may benefit from the high ash content of the organic waste briquettes. This is because ash of briquettes can be used for stabilization of soil, road base and manufacture of bricks among others. However, the contaminants such as heavy metals may impede the potential use of this ash in the soil. According to [28], the recommended heavy metal composition in briquettes fuel or charcoal range from 6.07 to 8.03 mg/kg for copper, 10 mg/kg is the maximum value for lead and cadmium ranged from 0.33

to 0.95 mg/kg. The values obtained were within the acceptable limits for lead and cadmium in organic waste feedstock used for briquette but copper content was higher. Hence, its use in soil may not be recommended.

3.3.4. Fixed Carbon Content

Table 3 also shows a summary of the fixed carbon content of the different briquettes and charcoal. One-way ANOVA test showed that there was a significant difference ($p < 0.05$) between fixed carbon content of briquettes and charcoal. Overall charcoal had the highest fixed carbon content (69.0%) compared to the briquettes produced (16.3% and 30.0%). Also, there was a significant difference ($p < 0.05$) in the fixed carbon content among the briquettes from various dumpsites with briquettes from education institutions having higher fixed carbon content 30.0% compared to briquettes from other places. Studies by [26] [39] reported higher fixed carbon content in briquettes that varied between 65% to 81%. These values are greater than this study's findings. Several studies recommended that acceptable fixed carbon content required for biomass fuel applications is about 80.5% [49]. However, the values obtained for fixed carbon in this study are below the recommended percentage. Therefore, the organic waste briquettes produced would not be fit as a good carbon fuel. However, the low carbon content in briquettes is an indication of good fuel for domestic energy applications.

[16] [50] [51] also observed lower fixed carbon content of briquette produced from rice husk varieties which ranged between 14.8% and 20.1%. The values they obtained are lower than this study's finding. According to [49] briquettes with lower fixed carbon tend to be harder, heavier and burn easier than briquettes with high fixed carbon. Therefore, this study suggests that the organic waste bounded with cassava binder and molasses binders are suitable for the production of briquettes that are harder, heavier and easy to burn.

4. Conclusion and Recommendations

This study assessed the concentration of heavy metal in municipal organic waste, a potential feedstock for domestic fuel briquette production in Kampala city. The findings from this study indicate that the concentration of heavy metals investigated was below the allowable limits while mercury was not detected. This implies that MSW from dumpsites sampled did not pose a health hazard arising from the presence of such heavy metals. Therefore, organic wastes are safe and can be used for briquette production. However, given the rather low calorific values of the briquettes produced, different ways of harnessing energy content of the waste should be investigated. Also, further research is needed to examine for the presence of the other heavy metals in the municipal waste not investigated in this study before it can be declared health hazard free.

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Conflicts of Interest

The authors declare no conflicts of interest regarding the publication of this paper.

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