Assessment of the potential of charred briquettes of sawdust, rice and coconut husks: Using water boiling and user acceptability tests

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**A B S T R A C T**

Charred briquettes production is a sustainable way of producing cooking fuel from waste. Unsustainable harvesting of wood for fuel production has contributed immensely to the rapid deforestation in Ghana. This study determined the potential of charred briquettes of sawdust, rice and coconut husks in meeting cooking energy needs of households. In a further step, the acceptability of biomass users in the study to replace their current fuels with charred briquettes was established. The calorific value of the charred briquettes was found to be 24.69 MJ/kg. The highest combustion efficiency of briquettes was determined as 34.7% when a multi-feed gasifier stove (MFGS) was used. There were 14% and 80% reduction in particulate matter and carbon monoxide emissions, respectively when briquettes was used instead of charcoal in the MFGS. The analysis of the production cost of briquettes revealed that 1 kg of briquettes should be sold at Gh¢ 2.48 in order to make a 10% profit. The user acceptability survey indicated that about 40% of respondents are ready to patronize briquettes should it be sold at Gh¢ 2.48. This study established that briquette is a suitable replacement for wood and charcoal, if its full potential is harnessed and the energy utilization efficiency of biomass (sawdust, rice and coconut husks) briquettes is confirmed.

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**Introduction**

**Background**

Energy consumption linked to non-renewable energy resources contributes to greenhouse gas emissions and enhances resource depletion. In this context, the use of agricultural and industrial solid residues such as rice husk, coconut husk, wheat straw, sugar cane bagasse, sawdust, wood shaving, forest residue among others, has been widely studied as an alternative energy source in order to decrease the use of fossil fuels [4,9,15]. Even though a lot of rice husks is produced, it is

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among the agricultural residues that are least utilized to obtain energy in developing countries. Approximately, 134 million tonnes of rice husks are produced annually in the world, of which 90% are burned in open air or discharged into rivers and oceans in order to dispose of them [21].

Also, in most developing countries, wood is used as a major energy source for the household (mainly for cooking), irrespective of the health implications. It is estimated that over 2.5 billion people in the developing world depend on biomass as their primary energy source for cooking [36]. Air pollution is increasingly becoming a major contributing factor of poor health in the world, especially respiratory diseases, of which the emissions from “dirty fuel” (e.g., wood) are one of the major contributors. For instance, a study by World Health Organization [32,37] indicates that the disease burden attributable to indoor smoke from solid fuels for developing countries is about 1.9 million premature deaths per year. Aside the health concerns, over exploitation of wood is also the major driver of deforestation and environmental pollution. Ghana has lost 85% of its forests in the last 100 years and has a deforestation rate of 2% per annum, one of the highest in the world, and 60% of this is used to meet wood demands [38]. This is because no concerted effort is made by the country and other less developed countries to introduce especially rural dwellers who find it economically impossible to switch from firewood to liquefied petroleum gas (LPG) to the use of processed agricultural waste fuel like briquette which they can produce by themselves. The use of renewable residue such as sawdust, coconut husk, and rice husk to produce cooking fuel can help reduce the pressure on forest resource. Besides the health and environmental concerns from the high usage of wood and charcoal, there are economic consequences such as loss of productivity and inefficient or inappropriate resource utilization. The loss of productivity may occur due to poor health as a result of polluted air or time spent in gathering wood at the expense of working or studying. Fossil fuel is also one of the available cooking energy sources. However, one of the drawbacks of burning fossil fuel is also air/environmental pollution. Burning any fossil fuel produces carbon dioxide, which contributes to greenhouse effect thus warming the earth, also the exposure to carbon monoxide can cause headaches and place additional stress on people with heart disease [39].

Coconut husk, rice husk and sawdust are bio-resources that can be safely converted into clean domestic fuel [31] in low income communities. The total global production of coconut in the year 2019 was 62.46 million metric tonnes [23]. The annual production of coconut, rice and timber in Ghana are 383,960 metric tonnes (0.61% of the world production of coconut) [19], 769,401 metric tonnes [16] and 3.7 to 6 million cubic meters [7] respectively. The clean conversion of bio-resources is important in Ghana, where more than 70% of households depend on biomass for cooking and water heating purposes [4,13].

Briquette is an energy source that can be produced from domestic, agricultural and industrial sources of biomass waste streams. Briquettes usage is sustainable, eco-friendly, healthy and not dependent on fossil fuel. The charring of feedstock prior to pelletisation into briquettes is capable of maximizing the calorific value and minimizing combustion emissions [26]. There is therefore, the need for the production of charred briquettes at low cost and in abundance to increase its potential to replace firewood, charcoal and fossil as a domestic cooking and heating fuels. Biomass briquettes do not increase the carbon footprints and are highly advantageous over other cooking fuels like wood in terms of quantum of heat generated per unit mass, moisture content, and storage space [12]. As Bonsu et al. [30] concluded, proper utilization of briquettes would help reduce climate change impacts, via the reduction in the over-dependence on wood for domestic and commercial heating. Besides, briquetting of agricultural wastes can improve sanitary conditions.

A study by Azasi et al. [10] discovered Brong Ahafo (now separated into Bono, Bono East and Ahafo Regions) is/are the region(s) in Ghana which has/have the potential to produce enough briquettes to meet local fuel demand. The reason for this great potential is attributed to the massive crop production and forest cover of the area. A research conducted by Akowuah et al. [5], assessed the physico-chemical properties of charcoal briquettes produced in Ghana and also established the demand of potential users and their willingness to substitute charcoal and firewood with charcoal briquettes. Similar research works were also conducted by Okot et al. [28], Kpalo et al. [17] and Martinez et al. [18] however, these previous research works on briquettes did not conduct field assessment of its potential as a high quality cooking fuel using reliable tests such as kitchen performance tests (KPT) and as well did not engage the people to use the product.

Therefore, the aim of this study is to determine the potential of charred briquettes of sawdust, rice and coconut husks in meeting the cooking energy needs of households through the direct involvement of households. The authors are further motivated to assess biomass users’ acceptability of charred briquettes in this study.

Theoretical foundation

Xiao et al. [25], Azasi et al. [10], Ahiduzzaman and Islam [2], and Obeng et al. [26] observed that increased use of charred briquettes from renewable biomass waste streams can significantly reduce deforestation, and harmful gas emissions. Azasi et al. [10] and Obeng et al. [26], also concluded that increased use of charred briquettes contributes greatly to energy sufficiency and fossil-fuel dependency reduction in Ghana. However, the increased use of charred briquettes, is affected by factors such as cost, availability, ease of use, quality and education on the benefits of using briquettes [30].

Gwenzi, et al. [14] proposed that, further research should be done in the areas of process optimization, cost estimation, and performance characteristics.
Materials and methods

Collection of feedstock

Sawdust, rice and coconut husks were collected from Tepa (Ahafo Region), Sunyani (Bono Region) and Techiman (Bono East) where large quantities of rice and coconut are grown and timber logged. These feedstocks are normally disposed of and mostly cause public nuisance and environmental pollution. Due to the fact that the feedstocks currently have no economic use and readily available, the research team collected them for free. It is however anticipated that if the briquette production and sales are scaled up; the feedstock will no more be free of charge.

Charring of feedstock

The charring was carried out at the Mechanical and Manufacturing Engineering Laboratory of University of Energy And Natural Resources (UENR), Sunyani, Ghana using a non-incineration device. The device used for the charring was a Multi-feed biomass gasifier stove (MFGS), an engineered device produced at UENR. Thousand six hundred grams (1,600 g) of each feedstock was weighed with the aid of an electronic balance as a batch for charring. The feedstock was put into the MFGS and charred for a period of 2.0 h at a temperature of 250 °C.

After the charring process, the product (solid charred sawdust, rice and coconut husks) was cooled and carefully poured into a storage container. Water was sprinkled on it for further cooling, to avoid re-ignition since the product is highly flammable. The process was repeated three times.

Production of briquettes

The charred feedstock was reduced in size and sieved with the aid of Tyler sieves to a size of less than 0.2 mm. Ajiboye et al. [3] found out that particle size of less than 0.2 mm is ideal for the production of briquettes. Starch from cassava was used as a binding material for the briquetting. The reason for using cassava as a binding material is its relative availability, low energy consumption and ease of preparation [29]. Also, cassava starch possesses the advantage of not causing smoking [1].

The ground and uniformly sieved sample of the charred feedstock was thoroughly mixed with the binding agent. The feedstock-binder mixture (of ratio 4:1) was fed gradually into a 30 mm internal diameter, 60 mm height mold of a locally manufactured plunger-type hand presser and compacted at a pressure of 89.14 kN/m². This pressure was used because it falls within the recommended compaction pressure proposed by Kpalo et al. [17].

Determination of physico-chemical properties of the briquettes

The physico-chemical properties of the charred briquettes such as calorific value, volatile matter content, moisture content, fixed carbon and ash content were determined. The calorific value was determined using a bomb calorimeter (TBTXRY-1A Oxygen Bomb Calorimeter) in accordance with industry standard [8].

Proximate analysis (a standardized procedure that gives an idea of the bulk components that make up a fuel) was conducted using the method recommended by Chaney [11].

Water boiling test (WBT)

This research adopted the water boiling test (WBT) developed by Global Alliance for Clean Cookstove (GACC) [41]. Charred briquettes and charcoal were used as fuel in the WBT. The parameters measured were combustion efficiency, particulate matter (PM) and carbon monoxides (CO) emissions.

KITCHEN performance test (KPT)

Laboratory testing even though is helpful in the determination of the performance of fuels, it is still inappropriate for verifying real-world performance of cookstoves or fuel. Real users do not cook in a controlled, repeatable, and reproducible scientific way. A study of some stoves and fuels, by Roden et al. [22] found that, field-measured PM emission for actual cooking were three times, those measured during simulated cooking in the laboratory. Hence, field-testing providing a kind of reality check on the performance associated with a particular type of fuel is essential.

One hundred (100) participants were visited at an interval of 24 h for 30 days to obtain daily measurements. Each household was assigned a number for identification. Participants also responded to questionnaires for each monitoring day.

Procedure for measurement of fuel consumption

1 Households were selected at random but the families’ willingness to participate was a factor. In rare cases when random sampling was not possible, households were selected as local circumstances allow [42]. The selected households were given samples of the briquettes and charcoal to cook (Yam, Banku, Groundnut soup, Porridge, Rice and Tomato Stew) to provide them with experience in responding to the questionnaire appropriately.
2 The fuel consumption for each household was also measured. The research team ensured that household members performed their cooking as close to their usual cooking procedures as possible [42]. The fuel consumption was measured by weighing the remaining charcoal and briquette after cooking the same quantity of a particular food.

3 Fuel saving due to switching from the use of charcoal to briquettes was evaluated using Eq. (1):

\[
\text{Fuel saving} = \frac{F_{cc} - F_{cb}}{F_{cc}} \times 100%
\]

Where, \(F_{cc}\) = consumption of charcoal
\(F_{cb}\) = consumption of briquette

**Estimation of potential of briquette production and demand**

Cocoa pods, oil palm residues, sawdust, cobs (maize), stalks (cassava) and husks (rice, sorghum, groundnut, millet, coconut) collectively has the potential as a feedstock for briquettes production. The list of feedstock presented by Azasi et al. [10] has been expanded to include cocoa pod [33], oil palm residue [33], coconut husk [27] and sawdust [43]. The potential of briquettes production from biomass waste was estimated using Eq. (2).

\[
M_{bp} = 0.4 \times \sum M_{(i)}
\]

where \(M_{bp}\) = Mass of briquettes produced (tonnes), \(M_{(i)}\) = Mass of biomass residue i, and 0.4 is the conversion factor since 60% of raw biomass is lost during its conversion to charred briquettes.

**Determination of user acceptability**

One hundred (100) households from the regions were sampled purposely for the survey. The selected households were each given five (5) kilograms of the charred briquettes and charcoal each. Questionnaires were administered to the representatives of the selected households before and after usage of the briquettes and charcoal. The data obtained from the survey were analyzed using Statistical Package for Social Scientists (SPSS version 20). Questions of critical importance which the potential users responded to included source of fuel, smoke production, cost of briquettes, ease of ignition of the briquettes, fuel savings and willingness to patronize briquettes.

**Results and discussion**

**Physico-Chemical properties of charred briquettes**

The results of the physico-chemical analysis of the mixture of charred sawdust, coconut and rice husks briquettes are presented in this section. The charred briquettes were cylindrical in shape with an average diameter of 30 mm and a height of 60 mm. The charred briquettes contained 25.72% fixed carbon, which is indicative of the available solid carbon in the fuel. This value is close to that obtained by Akowuah et al. [5] who reported a fixed carbon of 20.7% for charred sawdust briquette. The amount of fixed carbon in the fuel influences the heating value or calorific value of the fuel which was 24.90 MJ/kg in the case of the charred briquettes. The calorific value obtained by this study is higher than the minimum value set by the Wood Pellet Association of Canada (calorific value ≥ 16.0 MJ/kg). Similarly, this value corroborates the values obtained by Ajimotokan et al. [44] and Ugwu and Agbo [24] who reported calorific values of 24.9 MJ/kg and 23.6 MJ/kg, respectively. The volatile matter content of the charred briquettes was found to be 61.38%, which is high and explains why the charred briquettes is easily ignited. Ajimotokan et al. [44] determined the range of volatile matter content of charred biomass to be 41% to 78% which is in agreement with the value obtained in this study. The ash and moisture content which are inhibitive to combustion were relatively low at levels of 5.60% and 7.30% respectively. The ash content obtained in this study was satisfactory since it fell between the range (1.4% to 6%) reported by Ajimotokan et al. [44]. The moisture content obtained in this study falls within the range (5% to 10%) recommended by Aransiola et al. [45] and Pallavi et al. [46] for good quality briquette. These previous works observed that briquettes will easily ignite within this moisture content range.

**Combustion efficiency**

The combustion efficiency of wood charcoal compared with charred rice husk, coconut husk and sawdust briquettes showed that briquette had superior combustion properties (Table 2). The combustion efficiency increased from 13.1% to 31.2% when wood charcoal was changed to briquettes using coal pot as the cooking device. The efficiency also rose from 28% to 34.7% when charcoal was replaced with briquettes in the MFGS as the cooking device. The values obtained in this study compares favourably with those obtained in studies by Prasad and Verhaart [20] who reported fuel efficiencies for sawdust and rice husk to be in the ranges of 19.97 - 21.64%, and 26.20 - 27.27% respectively. The thermal power also increased when wood charcoal was replaced by briquettes in both cooking devices as shown in Table 1. These better performances of the briquettes as compared to wood charcoal probably are due to the superior energy density of briquettes.

The particulate matter (PM) emission decreased from 450.5 mg to 193.6 mg when wood charcoal was changed to briquettes using coal pot as the cooking device. The PM emission decreased from 3132.0 mg to 2705.1 mg when charcoal was replaced with briquettes in the MFGS as the cooking device. The carbon monoxide (CO) emission was significantly decreased from 126.3 g to 89.7 g in the coal pot and from 0.5 g to 0.1 g in MFGS cooking devices.
Table 1
Performance test result from WBT.

<table>
<thead>
<tr>
<th>Performance metrics</th>
<th>Coal pot wood charcoal</th>
<th>Briquettes</th>
<th>MFGS Wood charcoal</th>
<th>Briquettes</th>
</tr>
</thead>
<tbody>
<tr>
<td>Combustion Efficiency (%)</td>
<td>13.1</td>
<td>31.2</td>
<td>28</td>
<td>34.7</td>
</tr>
<tr>
<td>Thermal Power (kW)</td>
<td>6.2</td>
<td>7.5</td>
<td>10.1</td>
<td>12.9</td>
</tr>
<tr>
<td>PM to cook 5 L of water (mg)</td>
<td>450.5</td>
<td>193.6</td>
<td>3132.0</td>
<td>2705.1</td>
</tr>
<tr>
<td>CO Emission (g)</td>
<td>126.3</td>
<td>89.7</td>
<td>0.5</td>
<td>0.1</td>
</tr>
<tr>
<td>Replications</td>
<td>3</td>
<td>3</td>
<td>3</td>
<td>3</td>
</tr>
</tbody>
</table>

Table 2
Kitchen Performance Test (Fuel Saving).

<table>
<thead>
<tr>
<th>FOOD</th>
<th>FUEL CONSUMPTION(g)</th>
<th>CHARCOAL</th>
<th>Briquette</th>
<th>PERCENTAGE FUEL SAVING (%)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Yam</td>
<td>339.83</td>
<td>269.00</td>
<td>20.8</td>
<td></td>
</tr>
<tr>
<td>Banku</td>
<td>604.96</td>
<td>484.50</td>
<td>19.9</td>
<td></td>
</tr>
<tr>
<td>Groundnt soup</td>
<td>526.44</td>
<td>488.57</td>
<td>7.2</td>
<td></td>
</tr>
<tr>
<td>Porridge</td>
<td>200.83</td>
<td>104.61</td>
<td>47.9</td>
<td></td>
</tr>
<tr>
<td>Rice</td>
<td>260.72</td>
<td>203.16</td>
<td>22.1</td>
<td></td>
</tr>
<tr>
<td>Tomato Stew</td>
<td>370.08</td>
<td>313.00</td>
<td>15.4</td>
<td></td>
</tr>
</tbody>
</table>

Table 3
Cost Analysis.

<table>
<thead>
<tr>
<th>Materials and Equipment</th>
<th>Cost (Gh¢)</th>
<th>Quantity used for briquette (kg)</th>
<th>Quantity of briquette produced (kg)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Collection and transportation feedstock</td>
<td>2.00</td>
<td>15</td>
<td></td>
</tr>
<tr>
<td>Cassava starch</td>
<td>1.00</td>
<td>1</td>
<td></td>
</tr>
<tr>
<td>Purchasing and transportation of water</td>
<td>0.50</td>
<td>5</td>
<td></td>
</tr>
<tr>
<td>Pelletizing unit</td>
<td>2.00</td>
<td>N/A</td>
<td></td>
</tr>
<tr>
<td>charring unit</td>
<td>3.00</td>
<td>N/A</td>
<td></td>
</tr>
<tr>
<td>labour</td>
<td>5.00</td>
<td>n/a</td>
<td></td>
</tr>
<tr>
<td>Total</td>
<td>13.50</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

Kitchen performance test

The total fuel saving of the foods prepared during the Kitchen Performance Test is presented in Table 2. Porridge (from maize) recorded the highest fuel saving (47.9%), followed by Rice (22.1%) and the least fuel saving recorded was groundnut soup (7.2%).

Cost analysis

Cost calculations

The cost was calculated as direct material cost and operation cost. The direct material costs were listed as cost of Feedstock, cost of Starch and cost of water. The operational costs were cost of charring device (MFGS), cost of pelletizing device, labour cost, pyrolysis heat energy and cost of storage and packaging.

From Table 3, 1 kg needs to be sold on the market at a cost of Gh¢ 2.25 to break even. However, for a profit margin of 10%, the price should be placed at Gh¢ 2.48. From the survey (Fig. 1(d)), the estimated cost of the product is attractive to some of the respondents who agreed to buy it at Gh¢ 2.00 to 3.00 and those who were willing to pay beyond Gh¢ 3.00 for the charred briquette. Assuming that half of the respondents who agreed to buy the product at Gh¢2.00–3.00 are willing to pay Gh¢ 2.48 for the product, then about 40% of the respondents are ready to patronize the product. To improve on the patronage there is the need for public education and government policy initiatives to help make briquettes attractive especially to local users.

User acceptability

In most developing countries, people use firewood irrespective of thier awareness of the fact that firewood is unclean and very harmful to thier health. This study took cognizance of this situation and educated respondents of the questionnaires designed and administrated by this study and other people in the study area about the possibility of switching from harmful cooking fuels to more user and environmentally friendly ones. This education might have influenced the willingness of the
respondents especially the low-income earners to patronize charred briquettes. The willingness of respondents to patronize charred briquettes if they were readily available on the local market is shown in Fig. 1(a). Majority of the respondents (70%) indicated that they will buy and use charred briquettes for cooking even if the cost is higher than wood charcoal. The respondents who will use briquettes only if the cost is the same as wood charcoal formed only 25% and 5% were not willing to use briquettes at all. These results on the willingness to patronize charred briquettes show that briquette has a huge potential market. If public education on the strengths and opportunities of briquettes production and use is intensified nationwide, then the market share of briquettes can certainly be further improved.

Also, on fuel saving, 90% of respondents make savings from the use of charred briquettes (Fig. 1(b)). These good attributes of charred briquettes lead to the rating of the briquettes by respondents as excellent (10% of respondents), very good (70% of respondents) and Good (20% of respondents) as shown in Fig. 1(c). The percentage of respondents who were willing to
purchase briquettes at prices of GHS 1–2 and GHS 2–3 were both 40%. About 14% of the respondents were also willing to buy briquettes at GHS 3–4.

Potential of briquettes production

The Bono, Bono East and Ahafo Regions have the capacity to produce about 20,779.12 TJ of energy from waste biomass annually (Table 4). According to Azasi et al. [10], the local annual demand for wood and wood charcoal in these regions was 737.10 kt of wood (12,530.7 TJ of energy). It can therefore be concluded that, the regions can replace wood and wood charcoal with charred briquette effectively.

Conclusion

The sustainable production and utilization of charred biomass briquettes in Bono, Bono East and Ahafo regions of Ghana were determined. The calorific value of the charred briquettes was found to be 24.69 MJ/kg which is higher than than that of dried wood (17.9 MJ/kg). The combustion efficiency of briquettes was determined to be the highest (34.7%) when the MFGS cooking device was used. There were 14% and 80% reduction in PM and CO emissions respectively when briquettes were used instead of charcoal in the MFGS. Cost analysis revealed that 1 kg of briquettes if sold at GHS 2.48 can yield at least 10% profit. The user acceptability survey in this study indicated that about 40% of the respondents are ready to patronize briquettes if sold at GHS 2.48. The study also concludes that wood and charcoal demand can be satisfied using briquettes, if its full potential is harnessed.

Increased usage of briquettes can help reduce the pressure on forest wood currently being used for charcoal production and harmful emission into the environment. This study used a thermal gasification process to produce briquettes and assess its energy utilization and suitability. The results obtained by this study are therefore influenced by the method of charring. This study therefore contributes to knowledge in the field of briquette as all the previous works reviewed by this study used pyrolysis for the production of briquettes. Thus, a stage is set for the academic community to compare the physio-chemical characteristics of briquettes produced by gasification and other methods for charring briquettes. This study as well conducted a more reliable study in the form of field study to determine users’ acceptability of the product unlike the questionnaire-based survey used by a few other studies to determine same. It is recommended that public awareness on the usage of charred briquettes in Ghana should be intensified.

Declaration of Competing Interest

The authors declare no conflict of interest.

References


