BIOGAS POTENTIAL ASSESSMENT FROM A COFFEE HUSK: AN OPTION FOR SOLID WASTE MANAGEMENT IN GIDABO WATERSHED OF ETHIOPIA

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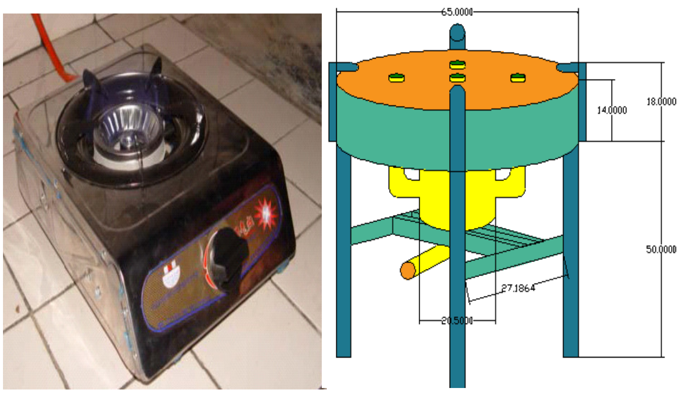
Abstract. The biogas and methane potential of a coffee husk at thermophilic and mesophilic conditions were examined. The tests were conducted using a laboratory bioreactors having a capacity of one liter, operated for about 40 days using a water bath thermostat at a temperature of 37 ± 2 ºC (mesophilic condition) and 52 ± 2 ºC (thermophilic condition). The biogas and methane production potentials of the two conditions were statistically different at $\alpha < 0.05$. The mesophilic condition produced 241.31 ± 10.29 ml·gVS^{-1} biogas and 131.67 ± 5.75 ml·gVS^{-1} methane after 40 days as compared with a biogas of 239.7 ± 12.97 and methane of 124.63 ± 6.7 ml·gVS^{-1} recovered after 20 days in the thermophilic condition; showing the former was better than the latter. The result prompted the viability of the coffee husk for biogas and methane production for better coffee solid waste management in Gidabo watershed of Ethiopia.

Keywords: thermophilic, mesophilic, methane, biogas, coffee husk.

Introduction

Over 85 % of the total energy demand in Ethiopia is covered from biomass, mainly charcoal and firewood [1]. Per capita annual energy consumption is about 16 gigajoules (GJ), among the least 16 countries in the world [1]. The energy generated is used for domestic activities such as cooking and space heating. However, a significant quantity goes to microenterprises like groceries and feeds retailers, processing of agricultural products, local beverage brewing, and restaurants. About 85 percent of families buy firewood (wood or charcoal) at an average cost of two USD a week [1]. The most accepted method of cooking in the rural part of the country is baking and boiling. This method is preferred to make bread or the Ethiopian traditional flatbread, *injera* as well as additives. Households often cook three times a day and at least twice daily at morning and evening. However there are localities where food preparation could only do once a day owing to energy shortages. If a biogas source is available, the existing rural cooking method is suitable for currently promoted energy efficient biogas stoves interventions in the country (Fig. 1). Lack of year round cow dung enough to run the existing biogas digesters and affordability are the major bottlenecks affecting farmers adoption of the intervention.



(a) (b)

Fig. 1. **Single burner energy efficient biogas stove in Ethiopia:** a – *SELAM* model cooking stove; b – schematics of Hawassa University *injera* stove

Next from petroleum, coffee is the second most valuable goods after petroleum. The coffee sector is one of the major economic and social development segment in the country [2]. Dry and wet coffee processing methods generate a high volume of solid waste (coffee husk, pulp) seasonally, causing serious environmental problems [3-5]. The solid waste having a considerable moisture content is disposed of in the receiving streams and fields without any significant vitalization or treatment. Gidabo watershed alone is a home for 276 coffee processing industries. During peak coffee production period (from September to January) in each of these wet mills, about 13.5 tons of cherries were threshed every day [6]. The good green coffee bean and the water content is about 20 % and 19.26 % each by weight. The remaining 60.74 % is the coffee husk [6]. These industries working an average of 60 days a year together generates about 135 790 tons of coffee husk annually. Disposal of the waste from the mills was usually carried out in the form of landfills.

With the increasing population size and the progressive inauguration of more coffee processing industries every year, the space allocated to coffee districts as a landfill to contain coffee waste are decreasing. Besides, it is observed that the waste disposed of and burned-off becomes a source of environmental and health hazards due to harmful greenhouse gasses released upon combustion and decomposition of organics [3]. Thus, the conversion of solid organic waste (plant and animal origin) into biogas, which is used as fuel for domestic energy generation, provides an eco-friendly solution [7,8]. All these calls for an immediate, cost-effective, efficient, and simple techniques to manage the solid waste without compromising the function of the environment. Hence, this study was meant to determine the biogas potential of coffee husk at a laboratory setup bioreactors and investigate the impact of temperature on the gas production performances.

Materials and methods

Material Analysis

Solids, referring to the dry matter in the coffee husk free from moisture, affects digestibility and suitability of the husk for biogas generation [9]. Solids with high nondigestible lignin concentration may not be suitable for microorganisms in biogas digester [10]. Therefore; total solids, fixed solids, and volatile solid analysis were conducted before the experiment using standard methods [11].

Total Solids (TS)

The amount of total solids in percentage was determined using equation (1) after evaporating the sample in a drying ceramic plate and desiccated to steady weight in an oven at 103 to 105 ºC for 24 h.

$$Total\ solids\ in\ \% = 100 \times \frac{DM_1}{FM}, \tag{1}$$

where DM_1 – the weight of the dry matter after drying at 105 ºC, g;
FM – weight of the fresh matter, g.

Fixed and Volatile Solids (FS & VS)

The dried sample from TS test was ignited to constant weight at 700 ^{o}C for four hrs under oxygen rich furnace. The remaining solids represent the fixed solid while the weight loss on ignition is the volatile solid (Equation 2 and 3).

$$Total\ solids\ in\ \% = 100 - Fixed\ solids\ in\ \% \tag{2}$$

$$Fixed\ solids\ in\ \% = \frac{DM_2}{DM_1} \times 100 \tag{3}$$

where DM_2 – the weight of the dry matter after drying at 700 ºC.

Bioreactors setup

Ten laboratory reactors washed with distilled water and ten oxygen freed gas bag of a known volume was used for the thermophilic (37 ± 2 ºC) and mesophilic (52 ± 2 ºC) setups (Fig. 2). Each reactor is filled with 200 ml of distilled water and 600 ml of inoculums. Ten gram of coffee husk was added in each of the eight reactors and the other two reactors left blank. All bottles were deoxygenated and connected to the gas bags using butyl rubber stoppers to prevent any gas escape. The experiment was conducted in two conditions: four replications with a mixture of coffee husk, inoculums, and distilled water; and one blank reactor with a mix of distilled water and inoculums alone was randomly picked and incubated in a water bath thermostat at a temperature of 37 ± 2 ºC, and the rest is incubated in another water-bath thermostat at a temperature of 52 ± 2 ºC. The reactors were prepared in 1:0.22 ratio of volatile solids (VS) of the substrate to inoculums in order maintain constant food to microorganism ratio. Inoculums were collected from the effluent of an active biogas reactor from nearby hotel.

Methane productions were measured by gas chromatography using flame-ionization detection and the production from the substrates was corrected for the amount of biogas/methane produced by the blank reactor. The samples were incubated until the methane production died out. All experiments were quadrupled, closed and placed in a water bath under dark condition. The temperature was maintained by an installed thermostat reading. The reactors were connected to a stand-by generator having a power blackout of fewer than 5 seconds to overcome frequent power failure during experimentations. The pH was measured initially and at the end of the experiment. Gas was regularly collected by gas bags and syringes of known volume. The reactors processes were sustained until no gas was detected in the gas bags. The precision balance was used to measure the mass of the ground husk. The volume of the gas was measured using syringe of 100 ml capacity.

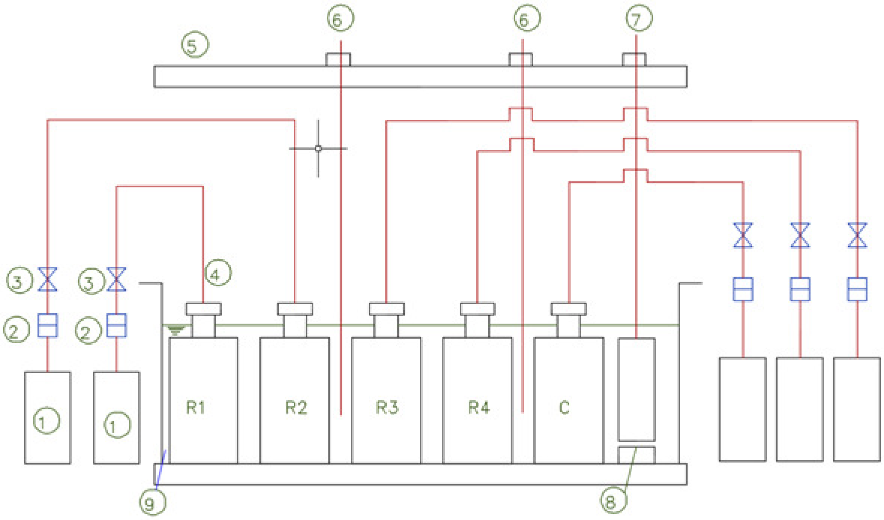


Fig. 2. **Schematic diagram of the experimental bioreactor setup for thermophilic (37 ± 2 ºC) condition:** 1 – gas bags; 2 – plugs; 3 – valves; 4 – flexible plastic pipes; 5 – cover; 6 – thermometers; 7 – stirrer; 8 – thermostat reading; 9 – thermostat; R1 to R4 – replicated bioreactors; C – control bioreactor; a similar setup was also employed for mesophilic (52 ± 2 ºC) condition

Randomized block design (RCBD) were employed. Determination of biogas potential of coffee husk at different temperatures (thermophilic and mesophilic) where each of the two treatments was replicated four times from R1 to R4 (Figure 1).

Data collection and analysis

The analysis was conducted using SPSS 20 and spreadsheet 2010. One way ANOVA at a significance level of $\alpha < 0.05$ was used to compare the variation among mesophilic and thermophilic gas production.

Results and discussion

Physicochemical characteristics of the solid waste and the inoculums

The solid waste has high organic matter content (Table 1). Feed materials consisting of a suitable proportion of carbon (TC) and Nitrogen (TN) are suitable for gas production [8]. The TC/TN ratio affects gas production and ratios of 20:1 to 30:1 are particularly favorable [9]. However, the coffee husks used for the current study have a TC/TN ratio of 93.49 (Table 1) which is significantly above the range of the feed material suitability for biogas generation. Therefore, it demanded nitrogen rich material for better performances.

The physicochemical characteristics of the inoculums were presented in Table 2. The observed lower pH value facilitated the acid-genesis phase of the process. The relative smaller proportion of VS and TS indicated a complete digestion except the active microorganism population in the inoculums.

Table 1

Characteristics of coffee husk collected from the wet mills

S./N.	Parameters	Values (Mean ± SD)
1	Total solid, %	88.26 ± 0.09
2	Volatile Solid, %	93.75 ± 0.5
3	Moisture Content, %	11.74 ± 0.08
4	Fixed Solid, %	6.25 ± 0.05
5	Total Carbon TC , %	40.19 ± 1.89
7	Total Nitrogen TN , %	0.43 ± 0.17
8	pH saturated extract	6.3
9	TC/TN	93.49
10	Bulk Density gm/cm^3	1.09 ± 0.04

Table 2

Characteristics of the inoculums

S./N.	Parameters	Values (Mean ± SD)
1	TS, %	8.67 ± 0.02
2	VS, %	6.13 ± 0.08
3	Moisture Content, %	91.33 ± 0.12
4	Fixed Solid, %	2.53 ± 0.06
5	pH	5.8

Note: TS – Total solid, VS – Volatile Solid

Albeit the carbon content makes the coffee husk (Table 1) a good feedstock for biogas production; concerns like the cellulose content of the husk, biodegradability, and volatiles concentration (like tannin, caffeine, and phenols) could inhibit the microbiological activities [9; 10]. Therefore, setting the reactors at different temperatures and observing the feasibility of the material as a feedstock for biogas plants were conducted and the results were presented in the following sections.

Methane and biogas production under mesophilic condition

Even though, the husk contains a significantly higher level of organic matter, the elevated proportions of organic matter were not deterred the gas production. On average the coffee husk gave 56.6 ml of biogas and 30.85 ml of methane every day from 10 grams of the substrate for 40 days showing the potential of the husk for gas production (Fig. 3). The gas production trends showed the highest gas production in the first week of the reactor operation. This confirmed that the raw coffee husk didn't inhibit the microbial community activity in the inoculums during the setup of the experiment.

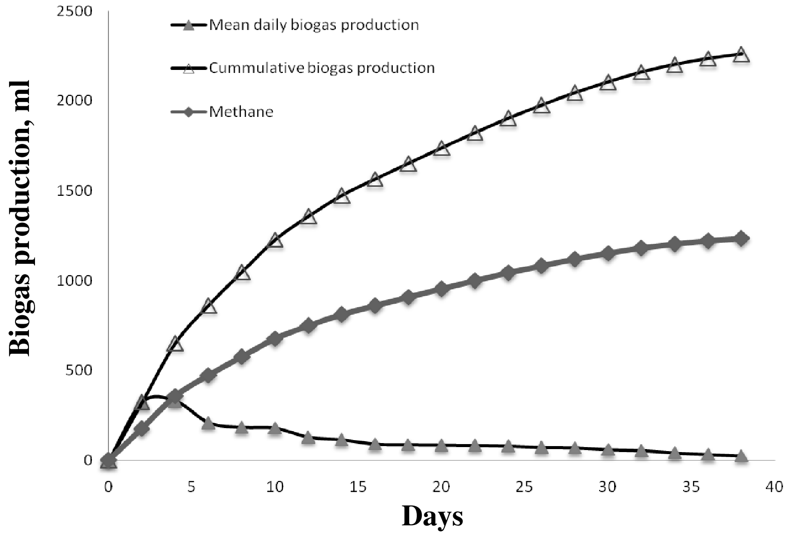


Fig. 3. **Daily and cumulative gas production from a coffee husk at a temperature of 37 ± 2 ºC**

Methane and biogas production at thermophilic condition

At the current condition, the coffee husk gave an average biogas of 112 ml and methane output of 58.42 ml every other day which is twice of the daily mesophilic yield (Fig. 4).

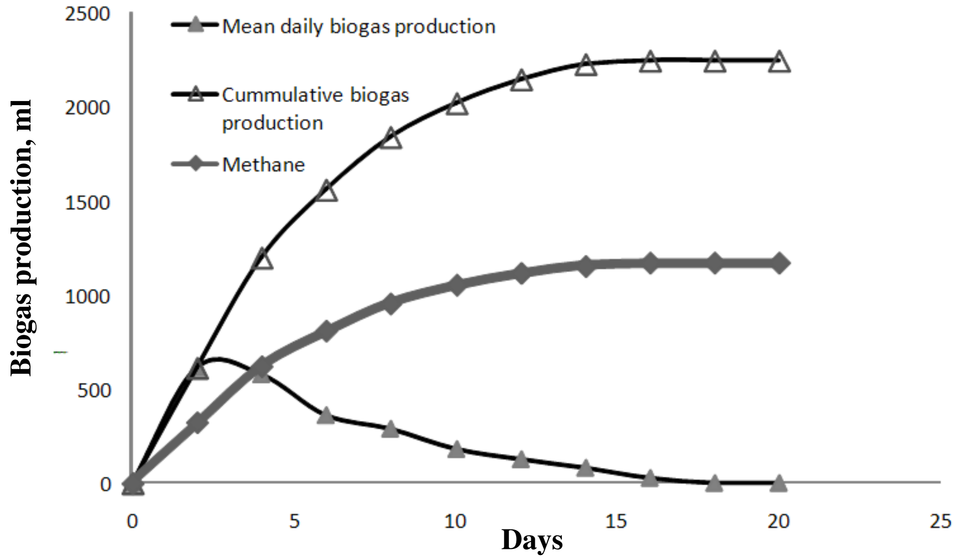


Fig. 4. **Daily and cumulative gas production from a coffee husk at a temperature of 52 ± 2 ºC**

However, the overall methane gas production of the thermophilic condition is slightly lower than mesophilic condition (Table 3).

Table 3

Mean biogas and methane outputs for thermophilic and mesophilic conditions

Condition	Biogas yield, l·kgVS^{-1} ($\alpha < 0.043$)	Methane ($\alpha < 0.0163$)	
		l·kgVS^{-1}	%
Thermophilic	239.7 ± 12.97	124.63±6.74	52
Mesophilic	241.31 ± 10.29	131.67±5.75	54.5

The elevated temperature in the thermophilic reactor facilitated the rate of biochemical reaction and doubled the daily gas production due to the increased activity of the microorganisms and the improved digestibility of the substrate. Moreover, the long retention time from the coffee husk under the mesophilic condition can be attributed to the high concentrations of nondegradable lignin and cellulose constituents [9; 10; 12].

The observed gas production (Table 4) is comparable to biogas and methane yield of solid organic wastes from the food, fruit, and vegetable industry [13-15] (Fig. 5).

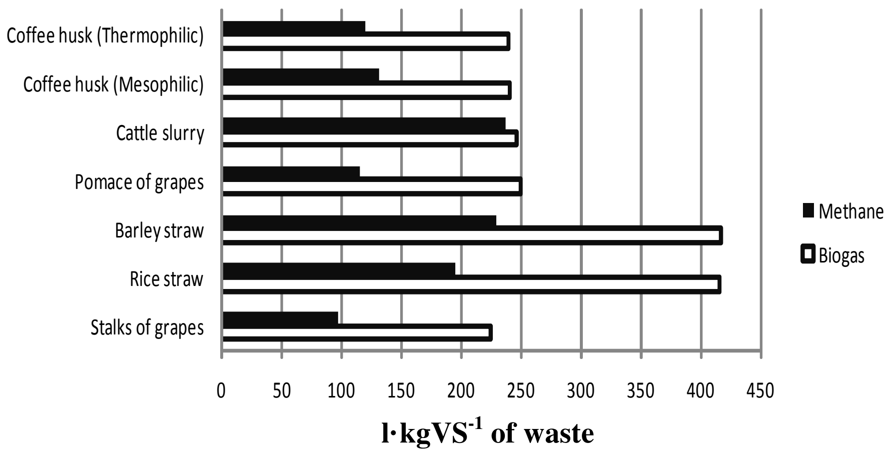


Fig. 5. **Comparison of biogas and methane potential of coffee husk (current research) with cattle slurry [13], pomace of grapes, barley straw, stalks of grapes and rice straw [14; 15]**

The actual rate of coffee husk digestibility and biogas recovery potential depends greatly on the reactor temperature and substrate composition [15; 16]. The thermophilic condition completed the bio-reaction process in 20 days, half lower than the retention time required by the mesophilic condition. Anaerobic bacteria under the mesophilic condition needed twice the time required by the thermophilic reactors to yield a slightly higher cumulative biogas and methane. However, the quality of the methane gas in the thermophilic condition is lower than the mesophilic condition. It is due to the higher water vapor load associated with the elevated temperature in the thermophilic condition. Owing to its higher carbon content, mixing the coffee husk with a nitrogen rich substrate may further enhance the digester yield [8]. Hence, amending the coffee husk with nitrogen rich mixes like chicken manure supplemented by higher digester temperature (thermophilic condition) can improve more gas production in a shorter time [8; 15]. Another scenario could be amending the coffee husk with nitrogen rich mix under mesophilic condition favoring quality methane gas production at longer retention time. For implementation, the shorter period favored by the thermophilic condition enhanced rapid throughput. However, the associated operational cost for reactor heating may lower its appropriateness as compared with none auxiliary energy demanding mesophilic condition.

With appropriate technical interventions, coffee husk can be used for biogas generation. In general, the management of coffee solid waste as an alternative to biogas digester feed material can minimizes the environmental pollution and reduce the overdependence of the community on firewood and animal residue for energy. It can also supplies an alternative energy source for wet mills too.

Conclusions

The study confirmed that biogas production as a possible option for energy generation concurrently resolving environmental problems. Even though it is considered as a waste by-product and a burden to coffee processing mills and the environment, coffee waste can be utilized as a feed for biogas reactors that can serve for different purposes in the industry and the community as well. As a result of its ample availability in the Gidabo watershed, the substrate may well be taken as a potential feedstock for biogas production in the rural areas, and also, be considered as suitable co-substrates to animal slurries to increase biogas yields. The highest methane yield from the experiment was achieved by the mesophilic condition with 131.67 ± 5.75 ml of methane from one gram of VS, whereas the thermophilic condition presented a slightly lower value of, 124.63 ± 6.74 ml of methane from one gram of VS, which is competitive with other straw and stalks based biogas feed materials. Therefore, the vast volume of coffee husk found in the different premises of the watershed needs to be biologically gasified and used as a substitute for the fuelwood and charcoal based household energy system of the community. This experiment also confirmed that the raw coffee husk fed into the reactor didn't harm the microorganisms brought to the system as inoculums.

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