

Energy analysis for small- and medium-scale rural rice parboiling in sub-Saharan Africa

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Abstract

Rice is a staple food in sub-Saharan Africa and many other regions of the world. There is a year-on-year increase in demand for rice in the region. Although there are some large-scale producers, most rice production in the region is by rural farmers and processing is done in small rural communities. Analysis of energy use in rice processing has become critical due to the dire consequences of deforestation and the increasing cost of fuel. Therefore, we studied the energy use pattern in medium- and small-scale rice parboiling outfits. Five sets of parboilers in the upper Benue River basin in Adamawa State, Nigeria were selected for the study: three small rural parboilers and two medium-scale suburban parboilers. A questionnaire was used to gather data, along with inspection of the firewood sizes and the stove used. Data gathering from the two medium-scale suburban parboilers involved on-site study. Two energy parameters involved in rice parboiling are human energy and thermal energy. Thermal energy comes entirely from firewood. The human energy use per kilogram of parboiled paddy was higher for the rural small-scale parboiling process than for the medium-scale parboilers. Energy use of the medium-scale parboilers was higher if they did not make use of the charcoal left after the complete combustion of the firewood. One of the reasons for this was the energy losses to the atmosphere, which were apparently very high for the medium-scale parboilers. The convection current through the stove was much higher for the small rural parboilers, leading to higher convection losses. The study reveals the need for optimized energy use for rice parboiling and it shows that in order for rural rice processing to be sustainable, energy sources must be carefully considered and the concept of recycling of fuel biomass should be integrated into the process.

Introduction

Rice parboiling is a significant step in rice processing. It involves temperature and hydration conditioning of the paddy before removing the hulls and polishing the final product through dehulling and milling. This is an energy-intensive process that requires manual and thermal energy. The thermal energy for this process comes exclusively from firewood, particularly in the northern part of Nigeria, and one of the most preferred sources is 'Kiriya' (*Prosopis africana*). Kiriya (the local Hausa name) is very important for farming and pastoralist communities in west Africa. The tree's physical and chemical properties make it attractive for local applications that include medicine, construction, energy, and manufacturing of handles for local tools. Its seeds are also used as food, while its succulent leaves and branches provide food for cattle and goats during the dry season. In addition, the trees fix atmospheric nitrogen that improves the soil fertility in the traditional parks and agroforestry system (Weber *et al.*, 2008).

Sustainability of the parboiling process is determined by the processing technique used and the energy source adopted. The scale of the process affects energy efficiency and capacity. The desired temperature for soaking is usually close to but below the gelatinization temperature of the rice. Bhattacharya (1985) proposes that the soaking should start at 70–75°C, allowing for cooling. After soaking, the rice is steamed for a certain period of time to completely gelatinize the starch. After steaming, the rice is dried, dehulled and milled. During parboiling, various physiochemical changes occur due to the gelatinization of starch granules in the rice. These changes play an important role in the next processing operation. Parboiling requires a specific amount of energy for the starch granules in the rice to be gelatinized, any excess energy supplied during this process is released to the surroundings (Weber *et al.*, 2008). The knowledge of how much energy is required in rice parboiling is important for optimization of the process, especially in rural communities where the process is based on traditional methods without consideration given to the exact temperature for gelatinization, heat loss to the atmosphere and the potential energy of the fuel used for this thermal process. The objective of this study was to determine the energy use pattern in medium- and small-scale rice parboiling outfits. It was also necessary to understand how energy efficiencies of the parboiling methods might be improved by use of waste biomass such as rice husks as alternative thermal energy sources.

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Materials and methods

Materials

The materials used during this research comprised a weighing scale, a measuring tape, thermometer, full-function weather station, digital camera, stopwatch, chain saw, local measuring pan called a 'mudu', kiriya firewood, and local variety of rough rice paddy.

Medium-scale parboiling

Medium-scale parboiling involves two processes. In the first soaking process, a locally made vessel of about 150 L is used. The vessel is placed on the stove that is created by using three blocks forming a tripod that supports the vessel and enables the placement of firewood underneath. During this process, an average of 132 kg (100 *mudu*) of rough paddy is poured into the heated vessel containing 100 L of water. Any floating immature paddy is removed and discarded. Three logs of kiriya firewood each of about 15–20 cm diameter are placed in the stove. The kiriya firewood is ignited and the soaked paddy is heated to a temperature of 52–84°C (thermometer completely inserted from the surface after quenching of logs). Then, the kiriya logs are withdrawn and quenched using water. The paddy is soaked for about 24 hours. The amount of logs consumed was determined by measuring the length of the consumed part of the log. The amount of charcoal and the ash were weighed to estimate the amount of unused energy. The second process involves steaming the paddy in a different vessel containing about 25 L water. The kiriya fuel stove is ignited and the steaming vessel is heated until the surface is completely covered with steam (temperature 83–100°C at the surface) for about 5–10 minutes, then the kiriya firewood is withdrawn and quenched. The rice is then dried on mats for about 24–36 hours depending on the weather conditions.

Small-scale parboiling

The small-scale parboiling is similar to the medium-scale parboiling, except that the size and type of the stove, vessels, and the size of the firewood are different. The stove is made of either three rocks or mud. In many cases, a locally fabricated circular steel stove that has an opening for firewood is used. The vessel is about 30 L and the processing batch is 10 *mudu* (13.2 kg) of rough paddy. The firewood comprises smaller stems of the trees or logs that have been split using an axe to 2.5–3.1 cm diameter sticks.

Estimation of energy consumption in parboiling

Thermal and human energy consumption were estimated during both rural small-scale and medium-scale parboiling. The thermal energy was estimated by measuring the amount of log that was consumed by the process, and the human energy was estimated based on the time spent working on the process.

Thermal energy consumption

The thermal energy E_t is estimated from W , the amount of firewood (kiriya) used and C_k , the heating value of kiriya using the following relationship:

$$E_t = C_k W \quad (1)$$

where heat capacity of kiriya, $C_k = 1720$ J/kg (Akaaimo and Raji, 2006) and the weight $W = \text{density} \times \text{volume}$. The density of kiriya is estimated as 680 kg/m³ based on the findings of Akaaimo and Raji (2006). Therefore, the amount of wood consumed is mathematically represented as:

$$W = \rho \pi d^2 \times L/4 \quad (2)$$

The parboiling efficiency of the process is determined using the findings of Islam *et al.* (2004), which suggested that energy requirement for parboiling rice is in the range of 4.0–5.5 mJ/mg; in this study, the upper value was taken to conservatively estimate the parboiling efficiency. The mathematical relation used to calculate energy efficiency is:

$$H = 5.5 \times 10^3 \times M \times (E_t)^{-1} \quad (3)$$

where M is the mass of the parboiled paddy. Using the *mudu*, which averaged 1.32 kg, equation (3) can be represented as:

$$\eta = (5.5 \times 10^3) \times 1.32 \times N_m \times (E_t)^{-1} \quad (4)$$

where N_m is the number of *mudus* parboiled.

In this analysis, the charcoal left is not accounted for, because it is not used in the parboiling process. Most of the charcoal is considered as waste. However, some of the parboilers indicated that the charcoal could become an attractive source of income as domestic fuel.

Human energy

Human energy was estimated using the values recommended by Waheed *et al.* (2008): human energy consumption is 0.30 kW with a mechanical conversion efficiency 25%, which results in 0.075 kW sustained in an 8–10 h workday. Mathematically,

$$E_h = 0.075 N \times t \text{ (kWh)} \quad (5)$$

where, N is number persons performing the mechanical task and t is the time it takes them to accomplish the task.

Results and discussion

Thermal energy consumption

The energy consumption of the medium-scale and the small-scale rice parboiling for 100 *mudu* (132 kg) of rice paddy are shown in Tables 1 and 2, respectively. The parboiling thermal efficiency of the small-scale rural parboilers was higher than that of the medium-scale parboilers. For the small-scale rural parboilers, the efficiency ranged from 21.94 to 44.83%, whereas for the medium-scale parboilers the range was from 19.90 to 27.89%. The low efficiency in the medium-scale parboilers can be attributed to various reasons; one key reason is the fact that the product of combustion contained a large amount of charcoal that was not used. The charcoal by-product ranged from 8.1 to 23.4% of the original expended firewood. In the case of the small rural parboilers, there was very little charcoal left, the combustion by-product was ash with traces of char. Another reason for the low parboiling efficiency of the medium-scale parboilers was the higher rate of energy loss to the atmosphere via the convective currents that flowed through the open tripod stove; radiative losses from the fire; energy losses to the atmosphere from the skin of the large vessel's wall; and evaporative losses from the top of the vessel, since it was usually left uncovered.

Table 1. Thermal energy analysis for small-scale rural rice parboilers

Small rural group	Firewood weight (kg)	Thermal energy used (kJ)	Thermal efficiency (%)
1	1368.2	2353.4	30.8
2	1264.0	2174.2	33.4
3	1338.8	2302.7	31.5
4	1816.0	3123.5	23.2
5	1345.2	2313.7	31.4
6	1127.4	1939.1	37.4
7	1300.3	2236.6	32.5
8	1125.2	1935.4	37.5
9	1486.1	2556.1	28.4
10	941.6	1619.6	44.8
11	1137.6	1956.7	37.1
12	1074.4	1848.0	39.3
13	1923.6	3308.6	21.9
14	1375.1	2365.1	30.7
15	1237.6	2128.6	34.1

Table 2. Thermal energy analysis for medium-scale rice parboilers

Operation no.	Firewood weight (kg)	Thermal energy used (kJ)	Thermal efficiency (%)
1	1594.4	2742.3	26.5
2	1775.6	3054.1	23.8
3	2121.5	3649.0	19.9
4	1716.7	2952.7	24.6
5	1545.0	2657.4	27.3
6	1679.6	2888.8	25.1
7	1513.6	2603.5	27.9
8	1806.4	3107.0	23.4
9	2001.1	3441.9	21.1
10	1910.2	3285.5	22.1

Human or manual energy consumption

The human energy consumption for the medium-scale parboilers ranged from 1.80 to 2.40 kWh/kg of parboiled rice (Table 3) — much lower than that of the rural small-scale parboilers, which ranged from 18 to 24 kWh/kg of parboiled rice (Table 4). The obvious reason for this is that medium-scale processors handle larger batches at a time for similar human effort compared to the small processors: small-scale parboilers handle 10 *mudu* (13.2 kg) per batch, whereas the medium scale parboilers handle 100 *mudu* (132 kg) per batch.

Table 3. Human energy analysis for medium-scale rice parboilers

Operation no.	Time (h)	E_h	
		(kWh per batch)	(kWh/kg)
1	4.3	0.3	2.4
2	4.1	0.3	2.3
3	4.2	0.3	2.4
4	3.7	0.3	2.1
5	3.6	0.3	2.1
6	3.8	0.3	2.1
7	3.2	0.2	1.8
8	3.8	0.3	2.1
9	3.7	0.3	2.1
10	3.6	0.3	2.0

Table 4. Human energy analysis for small-scale rural rice parboilers

Small rural group no.	Time (h)	E_h	
		(kWh per batch)	(kWh/kg)
1	4.2	0.3	24.0
2	3.9	0.3	22.0
3	3.9	0.3	22.0
4	3.9	0.3	22.0
5	3.9	0.3	22.0
6	4.0	0.3	23.0
7	4.0	0.3	23.0
8	4.0	0.3	23.0
9	3.2	0.2	18.0
10	4.0	0.3	23.0
11	4.0	0.3	23.0
12	4.0	0.3	23.0
13	4.0	0.3	23.0
14	4.0	0.3	23.0
15	4.0	0.3	23.0
16	4.0	0.3	23.0
17	4.0	0.3	23.0
18	4.0	0.3	23.0
19	4.0	0.3	23.0
20	4.0	0.3	23.0
21	4.0	0.3	23.0
22	4.0	0.3	23.0
23	4.0	0.3	23.0
24	4.0	0.3	23.0
25	4.2	0.3	24.0

Recommendations to improve efficiency and sustainability

The results show that operational parameters influence energy use and efficiency of the parboiling process. Methods for improving the sustainability of the overall process should be investigated. The areas to consider include the optimization of the energy utilization of the current process; use of combustible by-products from firewood combustion (i.e. charcoal for the parboiling process); and use of rice husks (a by-product of rice processing) as an alternative thermal energy source.

Optimization of the current process

Optimization of the current process would involve enclosing the stove. This will effectively minimize the convective and radiative energy losses to the atmosphere. This simple improvement would greatly improve parboiling efficiency. Another suggestion involves insulating the vessel and also keeping it covered. This would reduce the thermal losses to the atmosphere through evaporation and convection.

Use of the combustible by-products from firewood combustion for parboiling

The quenching and discarding of charcoal produced from the combustion of firewood is highly inefficient. The incorporation of charcoal as fuel would minimize the amount of firewood use. This could easily be achieved by establishing a continuous batch process that could use the charcoal as fuel for the soaking or steaming processes.

Use of rice husk as alternative fuel

The use of rice husk as energy source would enhance the sustainability of the overall parboiling process. A preliminary modified stove was tested. It uses rice husk as the key fuel and the charcoal from the medium-size parboilers as the starter fuel. The rice husk was placed in the stove bowl on top of a screen, and then a small amount of charcoal was placed and ignited on top of the rice husk. Within a few minutes (as the charcoal started to smolder) the rice husk ignited, producing a reddish-blue flame. Once the combustion commenced, all that was needed was to continue to add rice husk through the periphery of the stove. This stove is simple and burns cleanly, and it will be highly adaptable to the small rural parboilers.

Conclusions

Rice parboiling is an energy-intensive process. The small- and medium-scale parboilers in sub-Saharan Africa seem to overlook parboiling efficiency and sustainability issues that are associated with their current parboiling methods. This paper has shown that energy efficiency of parboiling depends on the operation scale and processing methods. The use of waste biomass such as rice husks as alternative fuel and modified stove may be key in ensuring sustainability of the parboiling process..

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