

RICE PARBOILING USING A DUAL-POWERED PARBOILER: EVALUATION OF ENERGY CONSUMPTION PATTERNS AND MILLING QUALITY

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Received: 27 February 2022

Revised: 20 April 2022

Accepted: 26 April 2022

Energy plays an important role in rice processing whereby the amount of energy consumed could influence the cost of production. Therefore, this study aimed to evaluate the energy consumption and milling quality of three rice varieties (FARO 15, FARO 60 and FARO 62) using a dual-powered rice parboiler. The energy consumption patterns viz steeping energy consumption, steaming energy consumption, total energy consumption and energy intensity of the rice varieties using electricity and Liquefied Petroleum Gas (LPG) combustion as the power source of the parboiler were determined using standard equations. The milling quality in terms of milling recovery and head milled rice were also determined using standard procedures. The energy consumption during steeping and steaming ranged from 39.02 MJ to 40.00 MJ and 12.90 MJ to 14.09 MJ, respectively. The total energy consumption and energy intensity ranged from 31.62 MJ to 32.01 MJ and 7.90 MJ/kg to 8.00 MJ/kg, respectively. The milling recovery and the head milled rice of the rice varieties ranged from 64.23% to 66.76%, and 55.45% to 59.18%, respectively. The total energy consumption and energy intensity of the rice varieties differ based on the power source of the rice parboiler. The power source also influenced the milling recovery and head milled rice of the rice varieties. The use of gas as a power source for the rice parboiler consumed more energy than electricity. The information provided in this study would guide energy conservation, prevention of production downtime and improving rice milling quality.

Keywords: energy consumption, milling quality, parboiling, rice varieties, dual powered parboiler.

INTRODUCTION

The grain that is consumed as a staple food by approximately half of the world's population is rice (*Oryza sativa* L.) (1). Rice grain is a good source of energy with starch as the main component. Rice parboiling is an ancient method in rice processing and is widely used in developed and developing countries such as India, Thailand, Nigeria, Ghana and some other rice exporting countries to improve rice quality, most especially before milling. Parboiled rice is produced both locally and internationally using traditional and modern methods. Parboiling is a hydrothermal process that involves steeping, steaming and drying operations that modify the qualitative and processing characteristics of rice (2). Steeping is a hydration process in which water diffuses into the paddy rice, and continuous water uptake leads to non-reversible swelling and fusion of starch granules (3). Steaming treatment during parboiling gelatinizes rice starch, improves the hardness of the rice during drying,

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minimizes breakage loss, and thus increases the milling output (1). The parboiling treatment also causes various physical and chemical changes in rice and it plays an important role in the subsequent storage, milling and cooking properties (4). For a rice parboiler to function, an energy source is needed to power it. In developed and developing countries, energy plays an important role in food processing. Energy comes from various sources such as solar energy, gas and electricity. It provides power for various processing and preservation equipment that humans use to produce, preserve and package food (5). Every year, approximately 59% of the total energy utilized in food processing is used for processes such as heating, dehydration, evaporation, and drying which consumes a lot of energy while about 48% of the total energy utilized is used for machines drive (6). Bhattacharya (7) worked on the energy required to parboil paddy rice using different parboiling methods. According to the study, the energy required for parboiling using Central Food Technological Research Institute (CFTRI) method, Rice Process Engineering Centre (RPEC) method and pressure parboiling methods were 1.64 MJ/kg, 0.954 MJ/kg and 0.375 MJ/kg respectively. Roy *et al.* (8) also researched the energy consumption of parboiling paddy rice in a laboratory-scale traditional parboiler. It was reported the energy consumed for parboiling was in the range of 1400 MJ/t to 2442 MJ/t, in which the values were concluded to be dependent on the treatment period. Some of these parboiling methods used equipment that erroneously supplied energy. Energy conservation in food processing is necessary to replace the higher consuming operations and increase the energy efficiency by adopting practical, economic and technical feasibility measures (9). Several researchers have attempted to develop numerous rice parboilers. Demont *et al.* (10) and Gbagbo *et al.* (11) fabricated an improved rice parboiler that operated based on wood biomass. Imonigie *et al.* (12) developed an electrically powered parboiler with a temperature controller. However, little has been reported in the literature about the development of a dual-powered rice parboiler that uses electricity and Liquefied Petroleum Gas (LPG) as a power source. In addition, information on energy consumption patterns viz steeping energy, steaming energy, total energy consumption and energy intensity, and milling quality on rice varieties produced under the influence of parboiling using a developed dual-powered rice parboiler is sparse. This study could provide a new idea on how to develop a dual-powered parboiler. Also, this study would be useful in the areas of energy conservation and prevention of the production of downtime should in case a source of energy is not available. Therefore, there is a need to evaluate the effect of parboiling on energy consumption and milling quality of rice using a dual-powered rice parboiler. This study aimed at evaluating the energy consumption patterns viz steeping energy, steaming energy, total energy consumption and energy intensity of three rice varieties using a developed dual-powered parboiler and also, to evaluate the milling recovery and head milled rice of the rice varieties.

EXPERIMENTAL

DESCRIPTION OF DUAL-POWERED RICE PARBOILER

Figure 1 shows the exploded view (a), pictorial view (b) and control box (c) that houses the electrical component of the dual-powered rice parboiler. The parboiling system majorly comprises a screen jacket, water level gauge, base frame, discharge valve, top cover, gas

burner, gas cylinder, electric heater and pressure gauge. The screen jacket is made of rectangular stainless steel that holds the paddy rice during steeping and steaming operations. The base frame is a four-legged structure that supports the weight of the parboiler. The pore size of the screen jacket is 1.5 mm, this is to retain the paddy rice during steeping and to allow the penetration of steam during steaming operation. The pressure gauge is a metallic tight lid with a narrow outlet that measures the pressure as a result of the steam generated in the parboiler. The discharge valve serves as a water outlet that controls the amount of water in the parboiling chamber. The G-clamp is a piece of metal that is used to fasten the top cover of the parboiler to its body. The top cover is one of the main components of the parboiler which is an openable compartment that allows the input and discharge of paddy rice. The gas burner supplied the thermal heat that is generated from the Liquefied Petroleum Gas (LPG) to the parboiler. The temperature controller is a plastic, with a glass-like screen that controls and regulates the temperature of the parboiler to prevent temperature spikes. The electric heating element is an electrical component that generates the electrical heat required in the system. The machine is equipped with two different power sources of energy which are the electricity source that uses the electric heating element and a gas burner that uses LPG to power the parboiler. The two sources of energy operate independently. If one is not available, the other source of energy can be used. The control box houses the main switch that electrically powered the parboiler and a temperature controller that signifies the set temperature and the temperature within the parboiler.

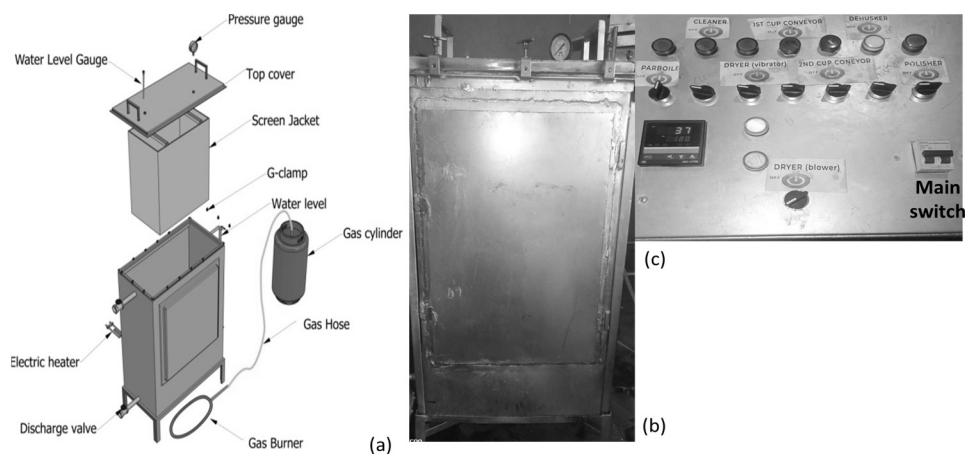
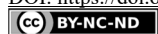


Figure 1. Exploded view (a), pictorial view (b) and control box (c) that houses the electrical component of the dual-powered rice parboiler

ENERGY CONSUMPTION AND MILLING QUALITY ANALYSIS

The paddy rice of FARO 15, FARO 60 and FARO 62 which are small, medium and long rice grains were obtained from the National cereal Research Institute, Baddegi, Niger State Nigeria and this study was conducted at the Department of Food Engineering, University of Ilorin, Nigeria. The rice paddies were cleaned to remove foreign particles. Rice varieties of 3 kg each were used for this study, 50 litres of water were charged into the par-



boiler and the electric heating element was switched on and the temperature was set to 80 °C. As the temperature of the water reaches 80 °C, 3 kg of FARO 15, FARO 60 and FARO 62 were introduced separately and allowed to steep until 28% moisture content of the paddy rice was achieved. The time taken to achieve 28% moisture content (wb) of the rice paddy was recorded for each rice variety. After achieving 28% moisture content, the water inside the parboiler was drained to 20 litres which is below the screen jacket and the remaining water in the parboiling chamber was heated to an above-boiling temperature to steam the paddy rice for 40 min. The time is taken for the temperature of the water to reach above-boiling temperature and the steaming time was also recorded.

For the Liquefied Petroleum Gas (LPG) combustion process, the same 50 litres of potable water were charged into the parboiler and the gas burner was ignited. The time taken for the water in the parboiler to heat up to 80 °C was recorded. Thereafter, 3 kg of each rice variety was introduced and the gas burner was switched off to allow steeping. The time to achieve 28% moisture content was recorded. In addition, the mass of the LPG used for the steeping process was recorded. After steeping, the water inside the parboiler was drained to 20 litres level below the screen jacket which was used to generate the steam required to gelatinize the steeped paddy rice. This process was achieved by heating the water to an above-boiling temperature and the steaming of the paddy rice also took 40 min using the gas burner. The mass of the LPG used and the time to heat the water to above boiling temperature was recorded plus the mass and time to achieve an additional 40 min of steaming. The steamed rice paddy of FARO 15, FARO 60 and FARO 62 was dried to 14% moisture content (wb) and was milled using a rice miller (Model MLNJ-15-13, India). The energy consumption patterns during steeping and steaming operations in the parboiler using the electrical mode of heating and gas combustion mode of heating were estimated by fitting data of labour, LPG combustion and electricity into Equations 1, 2, 3, 4, 5 and 6. Steeping and steaming energy consumption using an electrical power source were evaluated using Equations 1 and 2. Equations 3 and 4 were used to evaluate the steeping and steaming energy consumption using an LPG combustion power source. Equations 5 and 6 were used to calculate the total energy consumption for steeping and steaming using electrical and gas power sources and Equations 7 and 8 were used to evaluate the energy intensity using the electrical and gas power source. This approach to energy consumption determination was also reported by Sanusi and Akinoso (13). The milling quality of the paddy rice of FARO 15, FARO 60 and FARO 62 that were processed using the two power sources were determined in terms of milling recovery and head milled rice, respectively. These parameters were determined using Equations 9 and 10.

$$E_{se} = (0.68N \times 0.016t) + (3.6 \times P \times \emptyset) \quad [1]$$

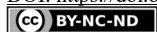
$$E_{ste} = (0.68N \times 0.016t) + (3.6 \times P \times \emptyset) \quad [2]$$

$$E_{sg} = (0.75N \times 0.016t) + (Qf \times Cf) \quad [3]$$

$$E_{stg} = (0.75N \times 0.016t) + (Qf \times Cf) \quad [4]$$

$$EC_{Te} = E_{se} + E_{ste} \quad [5]$$

$$EC_{Tg} = E_{se} + E_{ste} \quad [6]$$



$$EI_{te} = \frac{EC_{te}}{MP} \quad [7]$$

$$EI_{tg} = \frac{EC_{tg}}{MP} \quad [8]$$

$$MR = \frac{MMR}{MP} \times 100\% \quad [9]$$

$$HMR = \frac{MHMR}{MP} \times 100\% \quad [10]$$

where E_{se} is the energy consumption for steeping using electricity, E_{ste} is the energy consumption for steaming using electricity, E_{sg} is the energy consumption for steeping using gas combustion and the energy consumption for steaming using gas combustion (MJ) is represented by E_{stg} . EC_{Te} is Total energy consumption (MJ) using electrical power source, EC_{Tg} is Total energy consumption (MJ) using gas combustion source, N represent the average power in the tropical region of a male labour (0.75 MJ/h) (13), t is time taken to accomplish a unit operation (h), P is the power rating of the heating element in (W), ϕ is the power factor, MP is the mass of the paddy measure in kilogram, EI_{te} and EI_{tg} is the energy intensity using the electrical and gas power source (MJ/kg), MP is the milling recovery, MMP is the mass of milling recovery, $MHMR$ is the mass of head milling recovery, HMR is the head milled rice, Q_f is the quantity of the fuel (LPG) consumed and C_f is the constant of proportionality which represents the calorific value of Liquefied Petroleum Gas (LPG) (50.35 MJ).

STATISTICAL ANALYSIS

All the paddy rice samples were conducted in duplicate, and the results were expressed as the mean $\pm$ standard deviation. Analysis of variance (ANOVA) of the data was performed using Duncan multiple tests with a confidence interval of 95% in SPSS Software Package version 20 Chicago, IL, USA.

RESULTS AND DISCUSSION

ENERGY CONSUMPTION PATTERNS DURING STEEPING

Steeping is done in the parboiling process to achieve quick water absorption that could aid the proper gelatinization of starch in paddy rice. Figure 2 shows the steeping energy consumption patterns of three rice varieties using the dual-powered parboiler. The energy consumption pattern ranged from 39.02 MJ to 40.00 MJ using the gas combustion of the dual-powered parboiler while the energy consumption pattern using the electrical power source ranged from 17.02 MJ to 17.29 MJ. It was observed that the energy consumption using the electricity is lower than the gas combustion. This could be due to the stable temperature that was maintained when electricity was used to power the parboiler and thus facilitate the rate at which 28% moisture content of the paddy rice was achieved. However, in gas combustion, the temperature was unstable and thus could not be maintained, which contributed to a longer steeping time in achieving 28% moisture content. There was no sig-

nificant difference at $p>0.05$ in the steeping energy consumption values of FARO 15 (17.02 MJ), FARO 60 (17.13 MJ) and FARO 62 (17.29 MJ) when electricity was used to power the parboiler. However, there was a significant difference at $p<0.05$ in the steeping energy consumption of FARO 15 (39.02 MJ), FARO 60 (39.30 MJ) and FARO 62 (40.00 MJ) using the gas mode of operation. The difference could be due to the rate at which moisture content was absorbed by the paddy rice. Also, it might be due to the erratic nature of power provided by the combustion of gas. This result corroborates the findings of Arora (14) that energy consumption in steeping varies depending on the processing condition. However, the difference in the energy consumption during steeping based on the power source and paddy rice type could also be attributed to the processing time and rate at which water is sorbed in the void space between the husk and the kernel of the grain of the rice varieties. Bello *et al.* (15) also reported differences in the water uptake of rice grain via soaking.

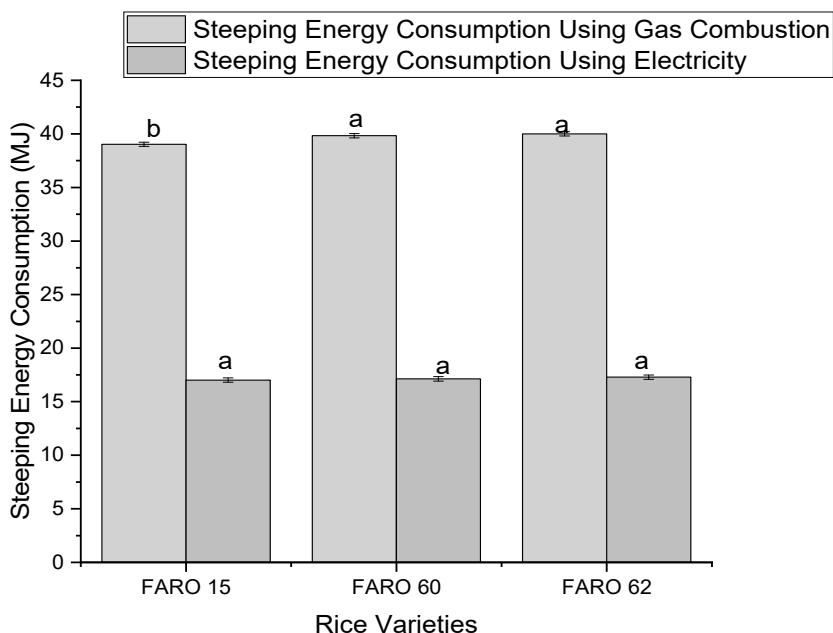


Figure 2. Steeping energy consumption patterns of three rice varieties during steeping using a dual-powered parboiler

ENERGY CONSUMPTION PATTERNS DURING STEAMING

Steaming is a key operation in rice parboiling processes which allows the gelatinization of rice starch, and thus leads to sealing and cementing of the cracks within the paddy rice which might have been caused during soaking. This causes the paddy rice to become harder thereby leading to higher milling quality and less breakage of milled rice. Figure 3 shows the steaming energy consumption patterns of three rice varieties using the dual-powered parboiler. The energy consumption pattern ranged from 12.90 MJ to 14.09 MJ when using

gas combustion of the dual-powered parboiler while the energy consumption pattern using electrical power source ranged from 14.61 MJ to 14.72 MJ. It was observed that the energy consumption using electricity was higher than gas combustion. This could be due to the differences in the processing time of the two-power source. There was no significant difference at $p > 0.05$ in the steaming energy consumption values of FARO 15 (14.61 MJ), FARO 60 (14.66 MJ) and FARO 62 (14.72 MJ) when electricity was used to power the parboiler. However, there was a significant difference at $p < 0.05$ in the steaming energy consumption of FARO 15 (12.90 MJ), FARO 60 (13.16 MJ) and FARO 62 (14.09 MJ) when gas combustion was used as the source of power. The difference could be due to the differences in the processing time of the rice varieties. Sanusi and Akinoso (16) reported that processing time has a significant influence on energy consumption during rice processing.

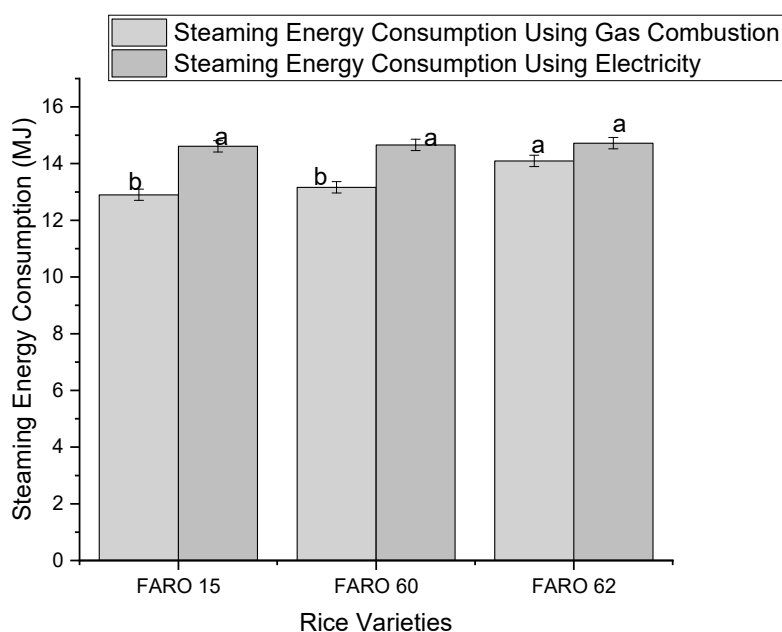
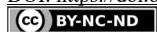


Figure 3. Steaming energy consumption patterns of three rice varieties using the dual-powered parboiler

TOTAL ENERGY CONSUMPTION

The total energy consumption of the dual-powered parboiler is the total amount of energy consumed during the steeping and steaming operations of a parboiling process. The total energy consumption using an electric power source differs from the gas combustion power source. Figure 4 shows the total energy consumption of three rice varieties using the dual-powered parboiler. The total amount of energy consumed using the gas combustion ranged from 51.92 MJ to 54.09 MJ while the total amount of energy consumed using electricity ranged from 31.63 MJ to 32.01 MJ. There was no significant difference at $p < 0.05$ in the total energy consumption of the rice varieties using gas combustion. It was observed that



the highest amount of energy consumed was in FARO 62 (54.09 MJ) and the least amount of energy was consumed in FARO 15 (51.92 MJ). For the electrical power source, FARO 62 (32.01 MJ) consumed the highest amount of energy. The least energy consumption was observed in FARO 15 (31.63 MJ). There were no significant differences at $p > 0.05$ in the total energy consumed in the rice varieties using an electrical power source. The difference in the total energy consumption observed between the two-power sources could be attributed to the difference in the processing time while for the rice varieties, could be due to differences in their grain size which might affect individual processing time. Roy *et al.* (17) reported a difference in energy consumption in parboiling paddy rice using local vessels, small boilers and medium boilers with 2583 MJ/t 2758 MJ/t and 1659 MJ/t respectively.

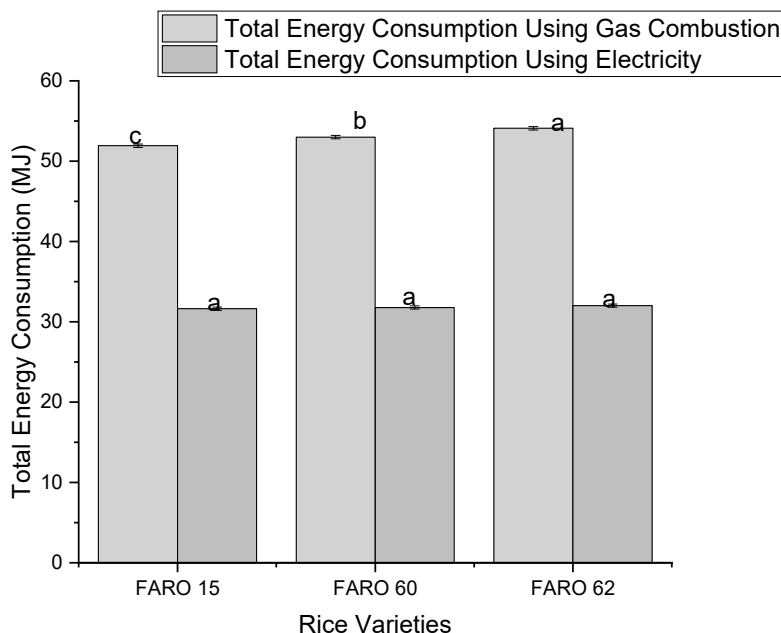


Figure 4. Total energy consumption of three rice varieties using the dual-powered parboiler

ENERGY INTENSITY

The energy intensity is the proportion of the total energy consumed to the mass of the paddy rice that was parboiled. The energy intensity using an electrical power source differs from the gas combustion power source. Figure 5 shows the energy intensity of three rice varieties using the dual-powered parboiler. The energy intensity using electricity ranged from 7.90 MJ/kg to 8.00 MJ/kg while the energy intensity using gas combustion ranged from 12.90 MJ/kg to 14.09 MJ/kg. There was no significant difference at $p > 0.05$ in energy intensity of the rice varieties using an electrical power source. It was observed that the highest amount of energy intensity using electricity was observed in FARO 62 (8.00 MJ/kg) and the least amount of energy observed was in FARO 15 (7.90 MJ/kg). Using the gas power source, it was observed that FARO 62 (14.09 MJ/kg) had the highest energy intensity while

FARO 15 (12.90 MJ/kg) was observed to have the lowest energy intensity. There were significant differences in the energy intensity of the rice varieties using gas combustion. The difference in the energy intensity observed between the two-power source and the rice varieties could be attributed to the difference in the processing time. Kapur *et al.* (18) conducted a study on the energy intensity used in rice parboiling. It was reported that paddy rice varieties that were processed using different parboiling methods have different energy intensities.

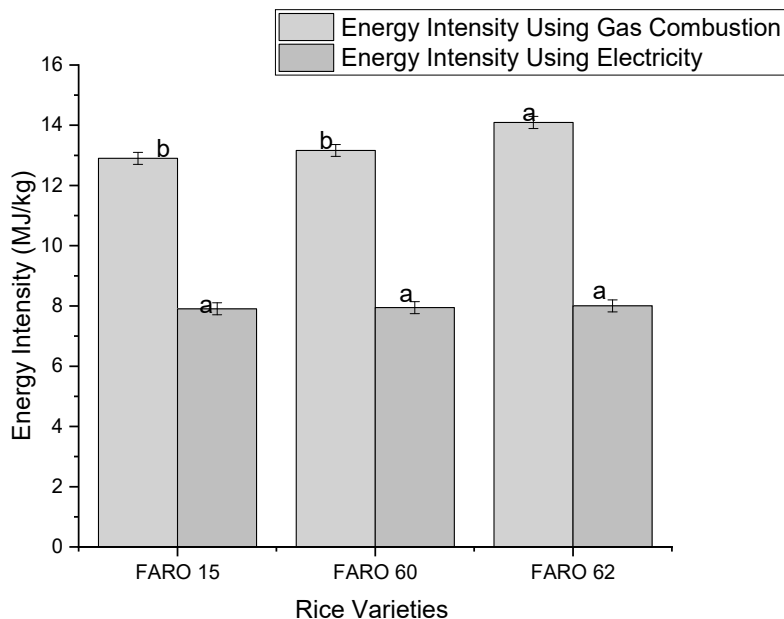
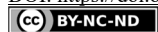


Figure 5. Energy intensity of three rice varieties using the dual-powered rice parboiler

MILLING RECOVERY

Milling plays an important role in rice processing because it determines the marketability of rice. Figure 6 shows the milling recovery using the dual-powered rice parboiler for three rice varieties. The milling recovery ranged from 64.20% to 66.45% when using the gas combustion of the dual-powered rice parboiler while the milling recovery values using an electrical power source ranged from 66.22% to 66.67%. It was observed that the milling recovery using an electricity source is higher than the gas combustion. This could be due to the difference in the processing approach based on the power source. The milling recovery recorded in this study is more than 60% reported by Gbagbo *et al.* (11) whose parboiler was powered with wood biomass. There was no significant difference at $p > 0.05$ in the milling recovery of FARO 15 (64.20%), FARO 60 (66.20%) and FARO 62 (66.45%) when gas combustion was used to power the parboiler. However, there was a significant difference at $p < 0.05$ in the milling recovery value of FARO 15 (66.22%), FARO 60 (66.47%) and FARO 62 (66.67%). The difference in the milling recovery of rice varieties could be attributed to the difference in the processing approach based on the power source.



buted to their level of starch gelatinization under the two methods of powering the parboiler and their ability to withstand milling pressure. This result corroborates with the findings of Akhter *et al.* (19) and Sanusi and Akinoso (1) that processing techniques influence the milling recovery.

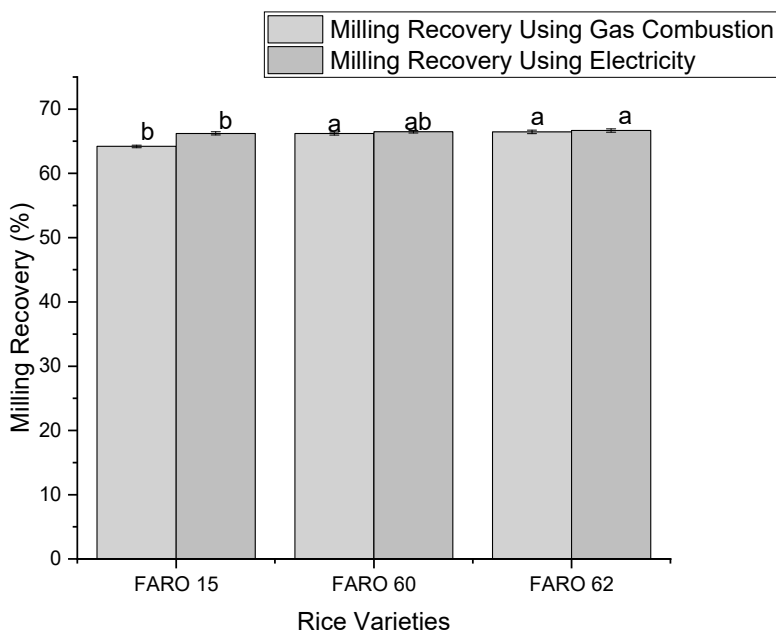


Figure 6. Milling recovery using dual-powered rice parboiler for three rice varieties

HEAD MILLED RICE

Figure 7 shows the head milled rice using the dual-powered rice parboiler for three rice varieties. The head milled rice ranged from 55.45% to 57.70% when using gas combustion while the head milled rice using the electrical power source ranged from 58.72% to 59.17%. The electric source gave head milled rice with a higher value than the gas combustion in the dual-powered parboiler. This could be due to the proper starch gelatinization and lower internal fissure while parboiling with electricity than in gas. The head milled rice obtained in this study while using electricity was higher than 58% reported by Gbagbo *et al.* (11) when wood biomass was used to power the parboiler. There was no significant difference at $p > 0.05$ in the head milled rice values of FARO 60 (57.45%) and FARO 62 (57.70%) when gas combustion was used to power the parboiler. However, there was a significant difference at $p < 0.05$ in the head milled rice value of FARO 15 (58.72%) and FARO 60 (58.75%). The difference could be due to the grain size, starch granules porosity and the level of the internal fissure of the rice varieties. Buggenhout *et al.* (20) and Sanusi *et al.* (21) reported similar findings in their studies.

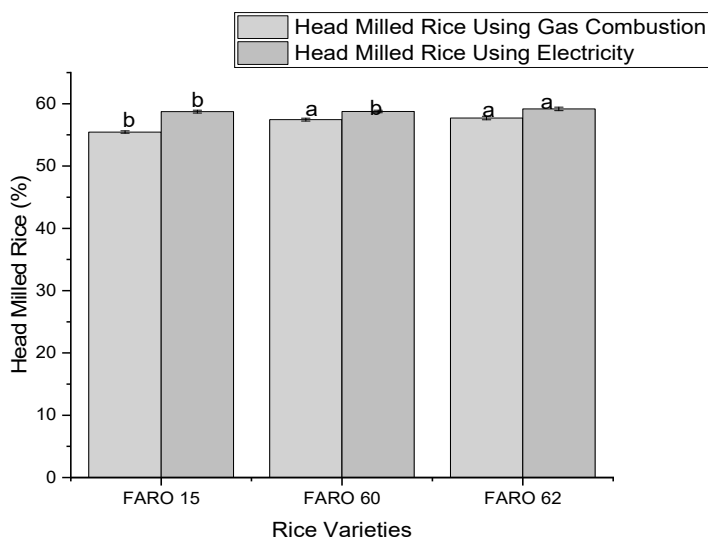


Figure 7. Head milled rice of the rice varieties using the dual-powered rice parboiler

CONCLUSIONS

The use of electricity and LPG combustion as the power source of a rice parboiler was used to determine the steeping energy consumption, steaming energy consumption, total energy consumption and energy intensity of three rice varieties. Using electricity to operate the parboiler showed less steeping energy consumption, total energy consumption and energy intensity, but more energy was consumed during steaming. The milling recovery and head milled rice of the rice varieties vary based on the source of power generation and paddy rice type. The use of electricity for the parboiler gave better milling recovery and head milled rice than gas combustion. Electricity power source aids better energy conservation in the rice parboiler than the use of gas combustion. Although the use of gas combustion could serve as an alternative source of energy when electricity is not available thus, preventing production downtime. Therefore, the information provided in this study would be useful for rice processors mostly in the developing countries in the areas of development of dual-powered parboiler, energy conservation, prevention of production downtime and improving milling quality.

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