Original Research Article

Design, Development and Performance Evaluation of a Paddy Rice Parboiling System

ABSTRACT

This study aimed to the development of a device for improve on parboiling techniques for rice farmers in Cameroon. The design and construction were carried out using an empty 0.2 m³ metal oil drum for the parboiler, which is made up of the soaking (0.1585 m³) and steaming (0.0919 m³) chambers with capacities of 0.1585 m³ and 0.0919 m³, respectively. The two chambers were divided by a perforated floor of 0.26 m². The performance of the developed parboiling device were compared with those traditional and industrial methods of parboiling. A water uptake test was carried out and a panel subjective test was used to compare the sensory and cooking quality of the rice for the developed parboiler, traditional and industrial parboiling methods. Results from this study showed that the developed parboiler used 2.5 kg of firewood to parboil 50 kg of rice in 2 hours 15 minutes at a soaking and steaming temperatures of 90 and 95°C respectively. The traditional parboiler used 9.8 kg of wood to parboil 50 kg of rice in 3 hours at a steaming temperature of 105°C. Panels' assessment showed that the quality of rice parboiled with the developed parboiler was good compared to the traditional and industrial methods. Overall results showed a significant improvement, less time of operation and a cheaper cost using the developed parboiler. This study concluded that there is no significant difference in the water uptake of the rice parboiled using the three parboilers at varying temperatures (P = .05). This developed parboiler is 5.4 times more efficient and 4 times greater in its construction cost than the traditional one. Local materials were valorized and the device was improved by the stove and the parboiler accessories which most parboiling devices do not have.

Keywords: Device, Paddy, Parboiling, Rice, Soaking, Steaming, water uptake.

1. INTRODUCTION

Rice (*Oryza sativa*) is well known for its hygroscopic behavior. However, it has been observed that the degree of swelling varies with varieties, unparboiled, parboiled rice and processing methods [1]. Rice being the second largest consumed cereal after wheat shapes the lives of millions of people; more than half the world's population depends on rice for about 80% of its food calorie requirements. Statistics indicate that Cameroon imported over 450,000 tons of rice mainly from Thailand, Vietnam, Pakistan, and Burma. Rice is the most consumed cereals after maize in all regions of Cameroon, mainly because it is cheap [2]. Total consumption needs are over 650,000 tons. Production of domestic rice is rising slightly due the government and donors' commitment to increase local production through a comprehensive rice strategy that has the financial support of multilateral donors including the World Bank and the international fund for agricultural development [3]. According to the national strategy for rice growing in Cameroon, rice consumption is estimated at 25.7 kilogram per person and growing at annual rate of 4 percent per year [4].

Parboiling is a postharvest rice transformation technic which consist of a hydrothermal treatment given to raw paddy. To parboil rice, paddy is soaked, heat treated and dried before dehulling to produce parboiled brown rice [5,6]. Parboiled rice contains high levels of B vitamins compared to milled non-parboiled rice [7]. Parboiling can be used to fortify rice with minerals and vitamins by adding them to the soaking water [8,9]. Presently in Cameroon, rural farmers who are the major producers of rice still parboil rice using the traditional methods of soaking the paddy in cold water overnight in a mud/clay pot or half drum for two or three days after which the paddy is steamed for hours and later dried and milled. This traditional parboiling process commonly results in improper gelatinization, discolouring and low market acceptability of the milled rice, due to defects and inadequacies in parboiling process. This necessitates the need to develop a paddy rice parboiler to improve upon the existing traditional method of parboiling in order to carry out parboiling operations within a short period of time and to get better quality rice with good market acceptability [4,10].

The parboiling techniques for paddy originated in India. It is now widely employed all over the world. It involves a hydrothermal treatment given to rough rice. As a result, the physicochemical properties of the rice are changed which affects the milling quality, nutritional value and storability of grain [11 – 17]. It consists of soaking, steaming and drying before milling. Parboiling results in significant changes in the physico-chemical and cooking characteristics of rice grain [18,19]. Basically, this is done to gelatinize the starch, remove air voids from the kernel and cement the cracks inside the endosperm. This process reduces milling breakage, facilitates disintegration of protein bodies, impacts hardness to the grains and makes them more resistant to fissuring by pest [20]. Parboiling is also important in reducing the losses of starch, vitamins, and minerals in cooking, destruction of infestation molds and insects, and inactivation of lipases to improve the shelf life of rice bran [7,21].

A survey was conducted in selected farm villages in four rice production zones of Cameroon. The survey was aimed at investigating the problems and difficulties faced by the farmers in paddy processing in order to find viable solutions to improve their income. A majority of problems were leading to cooking technics, marketing difficulties and reduction of crop yield followed by losses in the production chain, high costs for inputs, and lack of equipment for farming and processing, little or no knowledge on rice processing technics [4]. The survey determined that implementing improvements to the processing of paddy rice will increase local production of high quality rice for small-scale processors. This would encourage consumers to purchase competitive local parboiled rice and rely less on imported goods satisfying the demand locally [22]. Current parboiling practices are time-consuming and tedious process that does not necessarily produce large yields of parboiled rice. Traditional practices of parboiling rice require the firewood and water which are often in short supply. The need to improve existing parboiling practices is vital to maintain a sustainable rural economy for these small-scale producers. Hence, this study aims to design and build an improved paddy rice parboiling system for operation in a rural setting and to characterize the operational efficiency of the device.

2. MATERIAL AND METHODS

2.1 Location of study area

The study was carried out in Dschang, Menoua Division, West Region of Cameroon precisely in the Agricultural Engineering Research Unit of the Department of Agricultural Engineering of the Faculty of Agronomy and Agricultural Sciences. Dschang is located between latitude 5°25’ and 5°30’N and between longitude 10° and 10°5’E.

2.2 Design of the parboiling device

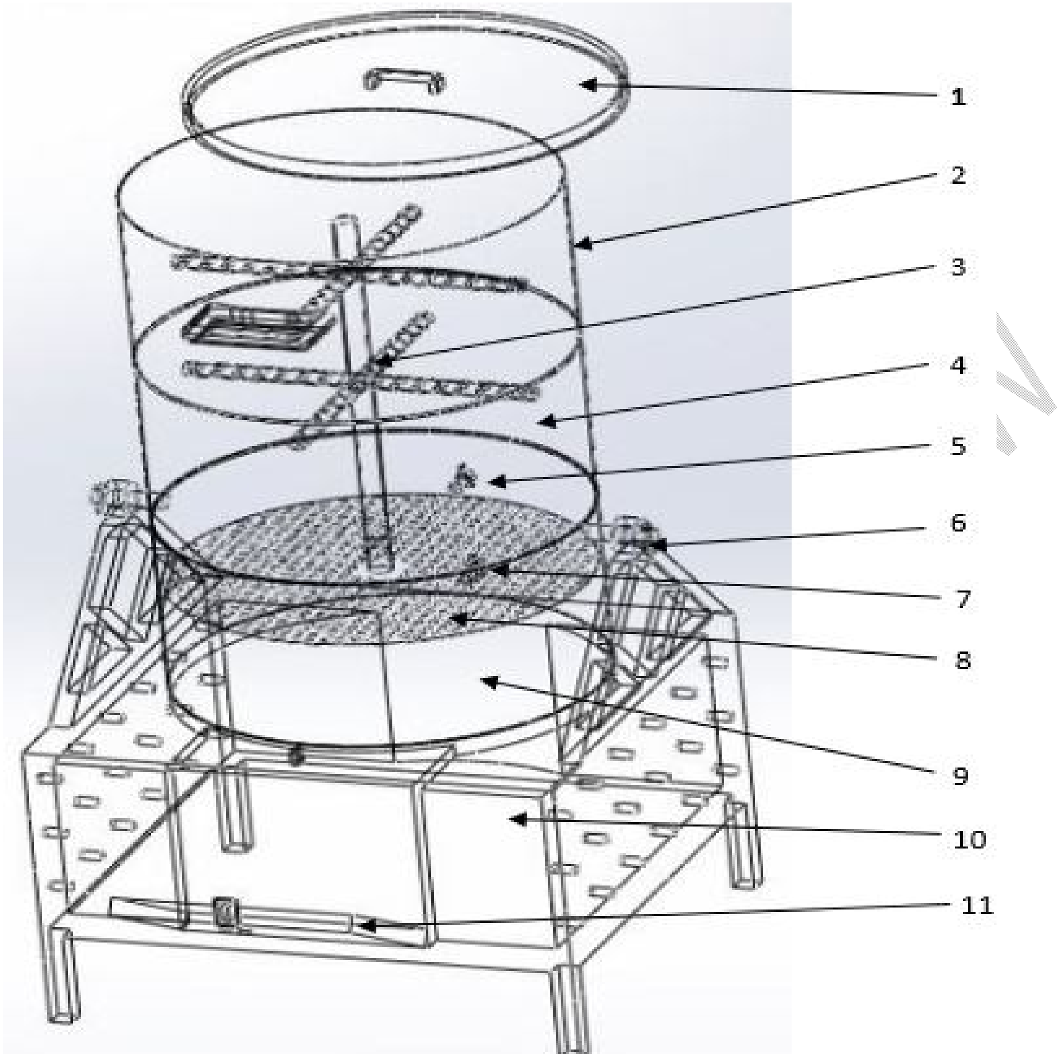
The rice parboiling device is made up of a standard 50 gallons (200 L) cylindrical drum, which is divided into two compartments by a false bottom plate. The upper part of the drum (the soaking chamber) is comprised of a cylindrical pipe and two sets of lateral pipes. These cylindrical pipes would ease the conveyance and the distribution of steam during steaming. The lower part of the drum (the steaming chamber) stands directly on the heating unit (the stove). The steaming chamber is comprised of two drain plugs (the upper and lower drain plugs) and water to heat the paddy rice during soaking and also to steam the rice during the steaming phase. During the operation of the parboiling device, the water is introduced into the steaming chamber and allowed to rise up to half of the soaking chamber. The stove is ignited to increase the temperature of the water to the required temperature before a clean, washed and weighed raw paddy rice will be introduced into the soaking chamber [23-24]. It is allowed to boil for a required number of hours at a given soaking temperature range which will be determined with the aid of a thermometer. Wood is used as the fuel for operating the device. The parboiler is mounted on a tilting frame which will serve as a stand and ease evacuation of the paddy after parboiling. The parboiler is designed to parboil a maximum of 50 kg of paddy per batch, and it occupies a surface area of 1 m^2. The design of the various components of the device (Fig. 1) was done using SolidWork.MBD and the Computer Aided Design (AUTO-CAD) soft wares.

2.2.1 Parboiler

The parboiler is made up of two principal chambers as explained: soaking and steaming chambers.

The soaking chamber is a circular tank which is made up of galvanized sheet. It has a diameter of 0.58m and 0.60m in height, giving a volume of 0.1585 m^3.

The steaming chamber is circular in shape made from galvanized sheet. It is located directly below the soaking chamber and has a diameter of 0.58m and a height of 0.30 m giving a volume of 0.0793 m^3. This chamber generates steam and has two outlet valves. The bottom outlet valve to drains out the water inside the steaming chamber while the steaming level indicator valve (upper valve) drains the water from the soaking chamber to its level for steaming operation.



1 Lid	**4** Soaking chamber	**7** Lower drain plug	**10** Support stand
2 Metallic drum	**5** Upper drain plug	**8** Perforated screen	**11** Stove's door
3 Heat conduit grid	**6** Tilting frame	**9** Steaming chamber	

Fig. 1. Sectional view of the parboiling device indicating its main components

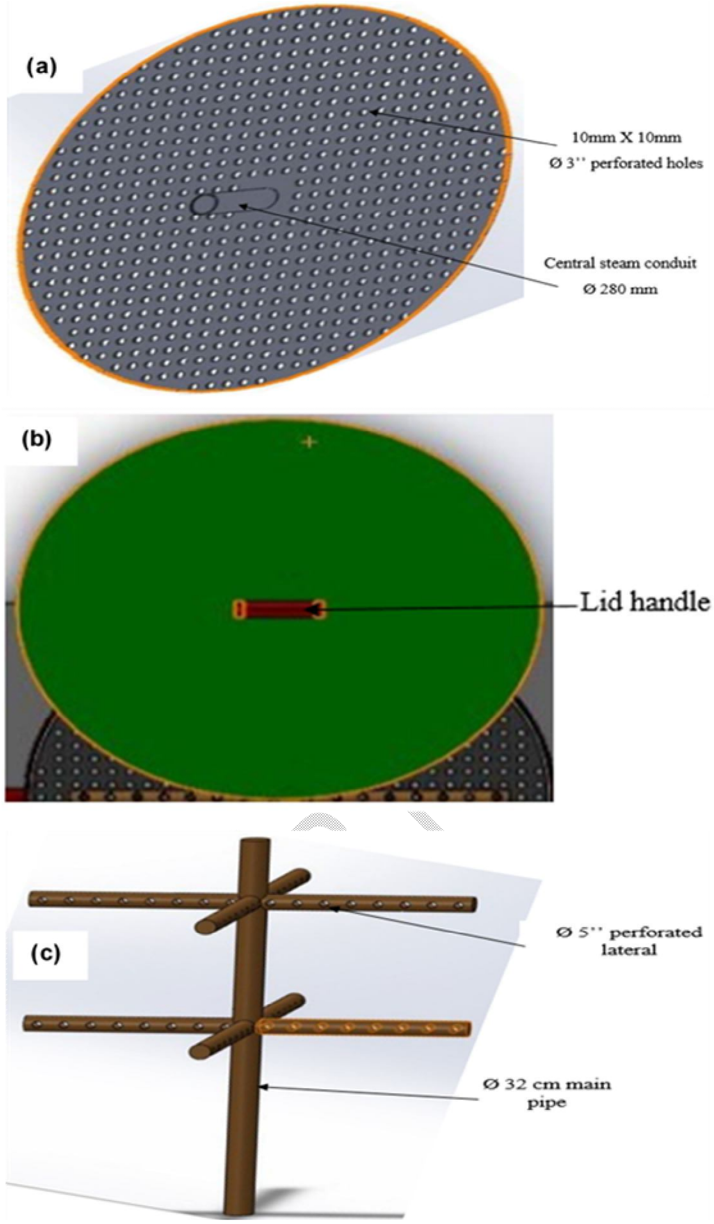
2.2.2 Parboiler accessories

Accessories were incorporated to modernize the device for a better operational efficiency. These accessories include: false bottom, parboiler cover and steam conveying pipe. The free space is a 0.10m gap between the soaking and steaming chamber which prevent the water from touching the soaked grains during steaming.

The false Bottom (Fig. 2a) is an inner circular screen that is perforated and incorporated inside the parboiler to the bottom of the soaking chamber to prevent the paddy rice from falling into the steaming chamber. It is made out of steel sheet and perforated with the help of a 3" mesh using a perforation machine.

The parboiler Cover (Fig. 2b) is also made from galvanized sheet which has a diameter of 0.58m used to cover the top of the device to prevent unnecessary escape of steam.

The steam conveying pipe (Fig. 2c) is made of a main cylindrical pipe made up of mild steel of thickness 0.0025 m and 2 pairs of 4 perforated laterals each. It is placed inside the paddy (soaking) chamber so as to distribute the steam effectively from the steaming chamber to the paddy chamber.



(a) False bottom **(b)** Parboiler cover **(c)** Steam conveying pipe

Fig. 2. Design of parboiler accessories

2.2.3 Parboiler stand

The parboiler stand is made up of the heating unit (stove) and the frame (Fig. 3). Each unit is designed as follows:

The heating chamber (stove) is a cube-like structure which consists of a 0.70 m x 0.70 m x 0.45 m height. It is constructed using 0.05 m x 0.05 m steel tubes. The sites are covered with iron sheets. The sheets are perforated for easy circulation of air to improve the flammability of the firewood in the stove.
The frame is a trapezoidal structure fitted on top of the stove. It is constructed of 0.003m thick iron angle bar. The top of the frames is fitted with a ball bearing each to hold the parboiler in an upright position of the stove and for rotation to ease evacuation of the steamed paddy.

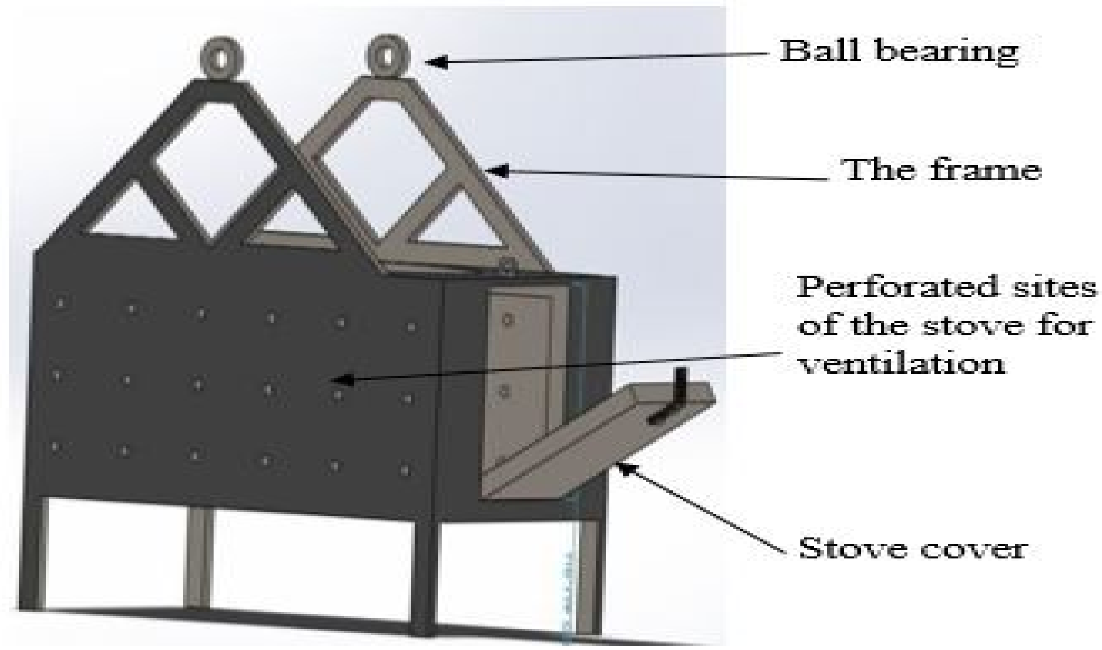


Fig. 3. Design of the parboiler stand showing the stove and frame

2.2.4 Design equations and calculations

2.2.4.1 Design equations of parboiler

The volume of the soaking chamber was given by the following equation:

$$V_{sc} = \pi r^2 h \quad (1)$$

Where:

V_{sc} = volume of the soaking chamber (m³)
r = radius of the parboiler (m)
h = height of the parboiler (m)

The weight of the parboiler was given by the following equation:

$$W = mg = \rho V g \quad (2)$$

Where:

W = weight of the parboiler (N)
$m = \rho V$ = mass of the parboiler (kg)
g = acceleration due to gravity ($m.s^{-2}$)
ρ = density of the parboiler ($kg\ m^{-3}$)
V = volume of the parboiler (m³)

2.2.4.2 Design equation of heat required

The amount of heat required to accomplish the parboiling operation was estimated using the following equation:

$$Q = MC_p\Delta T \quad (3)$$

Where:

Q = heat required for a parboiling operation (J)
M = mass of water required (kg)
C_p = specific heat capacity of water (kJ $kg^{-1}K^{-1}$)
ΔT = change in temperature (K)

To determine the mass of water required by using the relationship between the amount of paddy and the amount of water required. 1000kg of paddy requires 1300kg of water [25]. From this statement, it can be interpolated to get the mass of water needed.

2.3 Construction of the parboiler system's components

Once the concept and design of the parboiler and its accessories were set, the construction phase began. Building the parboiling device was performed in two phases: (1) prototype assembly and (2) workshop assembly. Phase 1 focused on building prototypes of each component of the system in order to become more familiar with the material used and building skills required to later build the parboiling device. Preliminary experiments were completed to test and improve functionality of the device. Phase 2 was the workshop construction (assembly) where in-depth experimentation on the parboiling device occurred (Fig. 4).

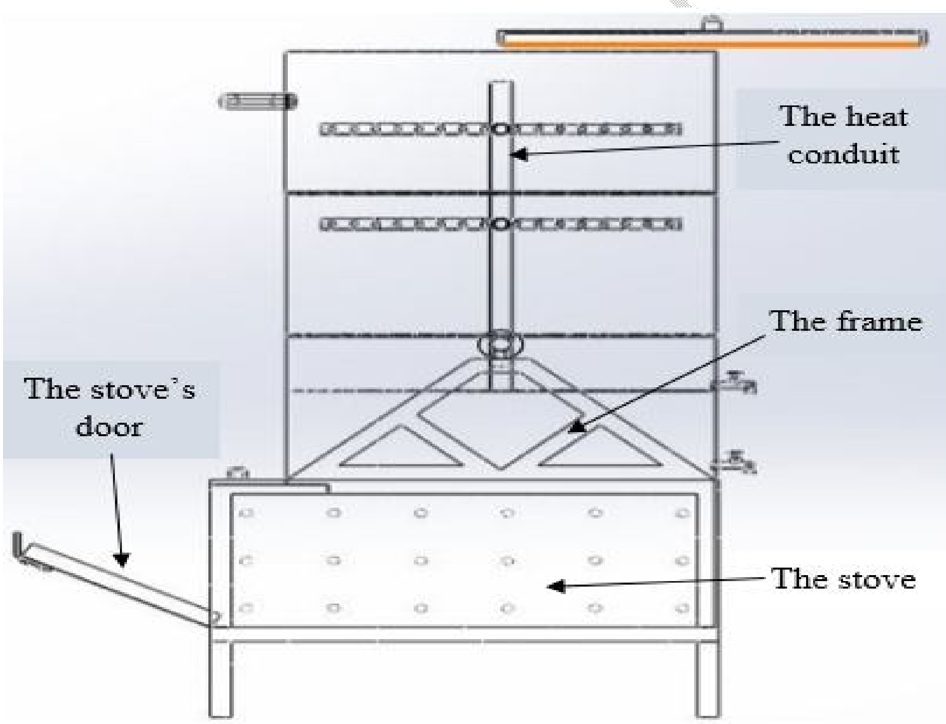


Fig. 4. Technical drawing showing the sectional view of the assembled designed device

2.3.1 Parboiler

The soaking and steaming chambers are made of a thin 24-gauge steel drum (0.02 inches thickness). The wall-to-wall and wall-to-base joints were soldered with a stainless steel flux paste. A similar process was done to make the lid of the soaking chamber. A small handle is welded onto the top of the drum to ease tilting and evacuation of the steamed paddy.

2.3.2 Stove

The stove measures 0.70 m x 0.70 m x 0.45 m. 2" thick 0.30 m x 0.30 m steel tubes and steel sheets were demarcated, and cut into their appropriate dimensions using a graduated tape and an arc sew. The various materials were welded using welding rods and were reinforced with bracings to render it firm. The bottom, top and sides of the stove were lined and covered with perforated mild steel sheets to minimize heat loss and ease flammability of the stove. The combustion chamber volume measures 0.147 m^3 (0.70 m x 0.70 m x 0.30 m). The stove was fitted with a 0.30 m x 0.20 m steel door with frames located at the front of the stove (used to feed fuel wood and collect ashes). The door's frame is made of steel tube and covered with mild steel sheet. They are welded together and connected to the door with a hinge. The door has a handle that rotates 90 degrees to lock the door closed.

2.3.3 Frame

The frame of the stand was constructed with 0.003 m x 0.003 m iron angle bars. It was measured, cut and welded using a graduated tape, arc sew and welding rods respectively. Bracings were welded and fitted with ball bearings to make the frame firm and to hold the parboiler in an upright position and rotation to ease evacuation

2.3.4 Perforated circular screen

The perforated circular screen holds the rice paddy. It is made up of food-grade stainless steel because it will come in direct contact with the paddy. The circular perforated base plate of 0.58 m diameter was dimensioned and cut from a stainless steel sheet of 0.60 m x 0.60 m. The plate was perforated using a 3 inches drilling mesh at an interval of one hole per cm^2. The center of the perforated plate is fitted with a 0.32 m diameter stainless steel pipe to conduct the heat to the upper part of soaking chamber for uniform heat distribution. It was welded to the walls of the metallic drum to hold it fixed and intact and to support the weight over it.

2.3.5 Steam conduit

The steam conduit is made up of a Ø0.032 mm main stainless steel pipe and Ø0.024 m laterals galvanize pipes. The main pipe measures 0.60 m and the laterals measure 0.26 m each. Each lateral was perforated with four column holes of 3 inches at 0.03 m between holes. The perforated laterals were welded to the main pipe in two sets of four laterals each.

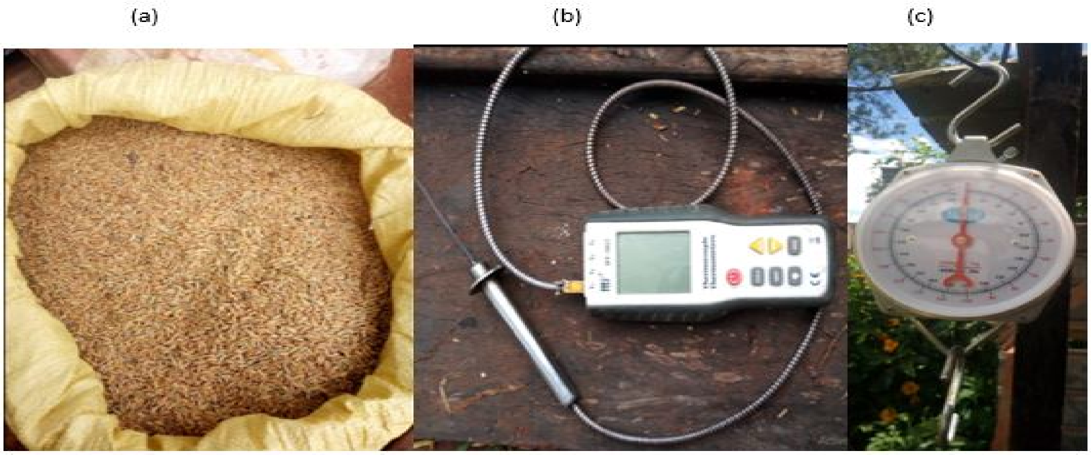
2.3.6 Drain valves

The drain valves were installed at the steaming chamber. The lower drain valve was installed at 0.001 m from the bottom and the upper drain valve was installed at 0.20 m from the bottom. The drain valves were welded to the steam chamber to avoid leakage.

2.4 Characterization of the device

2.4.1 Sample preparation

A set of 50 kg of paddy rice was cleaned (winnowed) and weighed with the help of scale balance. The paddy used for the experiment was of the NERICA variety (IR841). This paddy was washed in a basin with clean water. Floated grains were removed whilst stones and other debris settled at the base of the basin. After washing, the rice was kept in a basket to drain off water from the paddy mass (Fig. 5).



(a) NERICA paddy rice **(b)** Thermocouple **(c)** Scale balance

Fig. 5. Some of the sample and materials used

2.4.2 Parboiling process

2.4.2.1 Soaking phase

The parboiling equipment was mounted on the heating furnace and was filled with the required volume of water up to half of the soaking chamber. The furnace was ignited and the water was allowed to attain a temperature of 90 °C. The washed and drained paddy was poured into the hot water. On pouring in the paddy, the temperature of water-paddy mass was measured using a thermometer to ensure that it does not go below the soaking temperature of 80 °C as reported by [26]. The paddy was allowed to soak for 2 hours. Within this period of soaking, the temperature was not allowed to go below 80 °C and above 90 °C. After the soaking phase, the moisture content of the soaked paddy ranged between 30 and 35%.

2.4.2.2 Steaming phase

After soaking, the upper drain plug was opened to drain off the hot water from the soaking chamber (figure 3.25a). The heat was increased by reintroducing the quantity of firewood removed to heat the water to 100 °C in order to generate steam from the water in the steaming chamber of the device. As soon as the steam was observed from the upper chamber, the steaming was allowed to continue for 20 minutes, to complete the parboiling process i.e. the paddy had cracked from bottom to top. The steam temperature was measured to 95 °C using a thermometer.

2.4.2.3 Discharging of the steamed paddy

After the steaming, the lower drain plug was opened to allow water to drain off from the steaming chamber. Thereafter, the fire source was removed and the parboiler was tilted for easy evacuation of the parboiled paddy. The parboiled paddy was evacuated from the upper chamber by connecting a wooden lever to the bottom pipe and overturning the equipment.

2.4.3 Drying of the steamed paddy

The steamed paddy was allowed for vapour to completely leave the sample. The steamed paddy was spread on trays in the dryer at a thickness of 0.02 m. The drying was done in a temperature controlled dryer at 47±1°C and 60±5 % relative humidity resulting in the final moisture content of 13±1% wet basis. After drying, the sample was stored in airtight polyethylene bag for cooling, moisture equilibration and hardness stabilization as reported by Kimura [14].

2.4.4 Milling of the dried steamed paddy

After cooling, the parboiled paddy was milled using a rice milling machine to de-husk the paddy. The mixture was then winnowed to remove chaff and stones present. The milled rice was weighed and then sieved to remove husk particles. A kg of the milled rice was hand-picked to separate the broken grain from the whole rice and each was weighed accordingly.

2.4.5 Measurements and calculations of physicochemical properties

2.4.5.1 Milling efficiency

The milling efficiency is the ratio of weight of cracked grains after milling to the total weight of milled rice. It's mathematically given by the following equation:

$$E - \frac{W_c}{W_s} \times 100 \quad (4)$$

Where:

E = milling efficiency (%)
W_c = weight of cracked grains in a sample (kg)
W_s = total weight of milled grains in the sample (kg)

2.4.5.2 Head rice yield

The head rice is a grain that is longer than 3/4 of the total length of a whole grain. Head rice ratio is the proportion of head rice weight to weight of milled rice as shown by the following equation:

$$P_W = \frac{W_w - W_b}{W_w} \times 100 \quad (5)$$

Where:

P_W = head rice yield (%)
W_w = average weight of whole rice (kg)
W_b = average weight of broken grain (kg)

2.4.6 Sensory evaluation

The sensory evaluation included a cooking test, color, smell and taste [18]. It was performed by a panelist of 10 students between 18-22 years old. A scale of 1-5 was used, representing five categories as follows: bad, slightly good, moderately good, very good and extremely good.

2.4.6.1 Colour test

Brownness of the parboiled rice sample was measured using a RIPMAPP parboiled milled rice grading standard (v.4). Before measurement, the color paper was calibrated against standard brown to a percent brownness. Color of milled rice was measured as a function of the tristimulus factor values, using a "Color Difference Paper" Model JICA, Japan [23].

2.4.6.2 Cooking test

3 kg each of parboiled and raw rice were prepared together with the panelists. The rice was washed with 3 different portions of clean water while 3 litres of water was allowed to boil at 95 °C in a pot. The washed rice was poured into the pots. Measured volumes of water were added during the cooking process and time taken for it to be cooked to the same texture was also recorded. Weight of the cooked rice was taken to determine the water absorption, swelling index and volume evaporated during the cooking test. Water absorption was calculated using the following equation:

$$W_a = \frac{C_s}{R_s} \times 100 \quad (6)$$

Where:

W_a = water absorption (%)
C_s = weight of cooked sample (kg)

R_s = weight of uncooked sample (kg)

2.5 Statistical Analysis

The parboiled brown rice treatment and all analyses were performed in triplicate. One – way analysis of variance (ANOVA) was used (significance level P = .05) to analyze data by using the SPSS (Statistical Analysis System Software) version-11.

3. RESULTS AND DISCUSSION

3.1 Designed parboiling device

3.1.1 Designed calculations

Several data were used in the designed calculations for the development of the rice parboiling device. Table 1 shows calculations parameters and constants used for the calculations.

Table 1. Calculations parameters and constants used

Parameter	Unit	Quantity
Quantity of rice to be steamed per batch	kg	50
Bulk density of paddy (Champ and Highly, 1986)	Kg m^{-3}	571
Density of mild steel (hyper text book. Com)	Kg m^{-2}	7.85
Quantity of water required for 1000Kg of paddy (Wimberly, 1983)	kg	1300
Diameter of steamer	m	0.58
Clearance for the steam circulation below false bottom (Gbabo 2001)	m	0.01
Diameter of the soaking chamber	m	0.58
Required soaking duration	hrs	2
Required soaking temperature	°C	80-90

Assuming excess volume (clearance) between the top drain plug and the false bottom required for steam generation is approximately 33% of actual volume of the steaming chamber. The volume of water required to soak 100 kg of rice and assuming 50% of excess water is required for parboiling rice.

3.1.2 Heat required for parboiling of paddy rice

According to Wimberley [27], the mass of water required for 50 kg paddy rice is 65 kg. Adding of 40% of water for parboiling of the paddy rice and 10% absorbed after soaking (32,5 kg), the total mass of water need is 97.5 kg.

Using equation (3), the quantity of heat required to boil 97.5 kg of water both for soaking and steaming a batch of 50 kg rice is the following:

Q = 97.5 kg x 4200 J kg^{-1} K^{-1} x (373-277)K = 39312 kJ

Assuming a 50% heat loss during the process of parboiling, therefore, actual heat required equal expected heat loss plus heat generated.

Q' = 39312 + 19656 = 58968 kJ

Table 2 shows the calculations of designed device components.

Table 2. Designed device calculations

Parameters	Quantity	Units
Volume of soaking chamber	0.1378	m^3
Volume of steaming chamber	0.0919	m^3
Total volume of parboiler	0.2297	m^3
Weight of parboiler	2.24	kN
Amount of heat required	58968	kJ min^{-1}
Area occupied	0.5625	m^2

According to Table 2, the volume of the soaking chamber is the sum of the volume of paddy required for soaking per batch (50 kg) and the excess volume allowed for soaked rice expansion and steam circulation which is assumed to be 10% of the paddy volume.

3.2 Constructed components of the device

3.2.1 parboiler

The steaming and soaking chambers (Fig. 6) are divided with the help of the perforated false bottom. The soaking chamber is designed to soak a batch 50 kg paddy rice during the parboiling process. The soaking chamber is lined to the bottom by perforated screen and a steam conduit grid. The perforated screen is welded to the walls of the drum on top of the steaming chamber and the soaking chamber is held in an upright position by the frame with the aid of pipe and bearings fixed together to ease evacuation of parboiled rice.

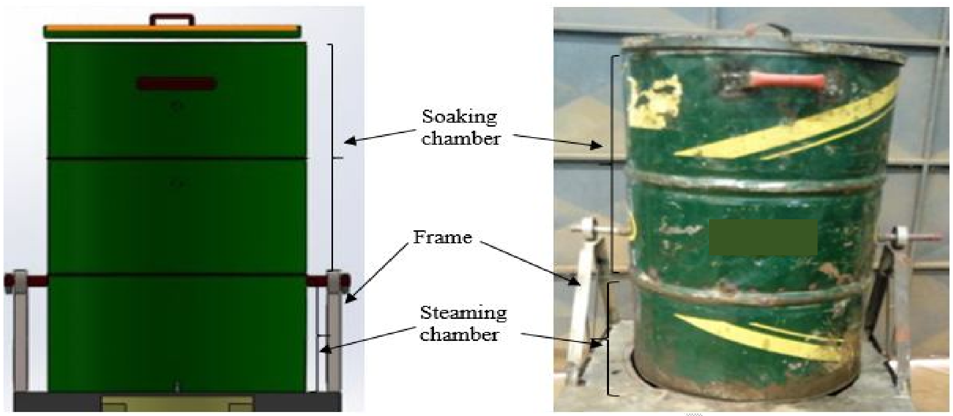


Fig. 6. Mild steel drum parboiler showing the two chambers and the frame

3.2.2 Parboiler accessories

3.2.2.1 Steam conduit grid

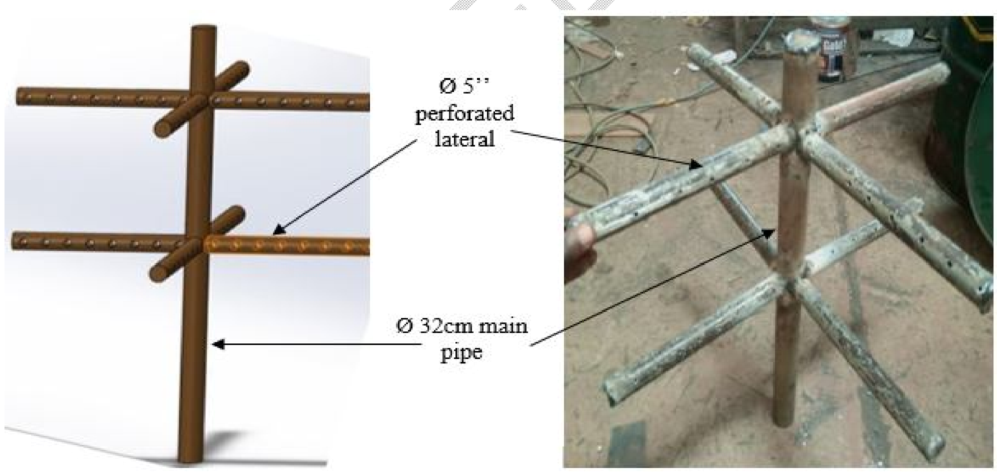


Fig. 7. Steam conduit

The grid (Fig. 7) is made to serve as the stirrer by uniformly distributing steam inside the paddy during parboiling. The main pipe passes through the center of the steamer through the false bottom screen above the steamer. The cover (lid) is used at the top of parboiler to prevent escape of steam.

3.2.2.2 False Bottom perforated screen

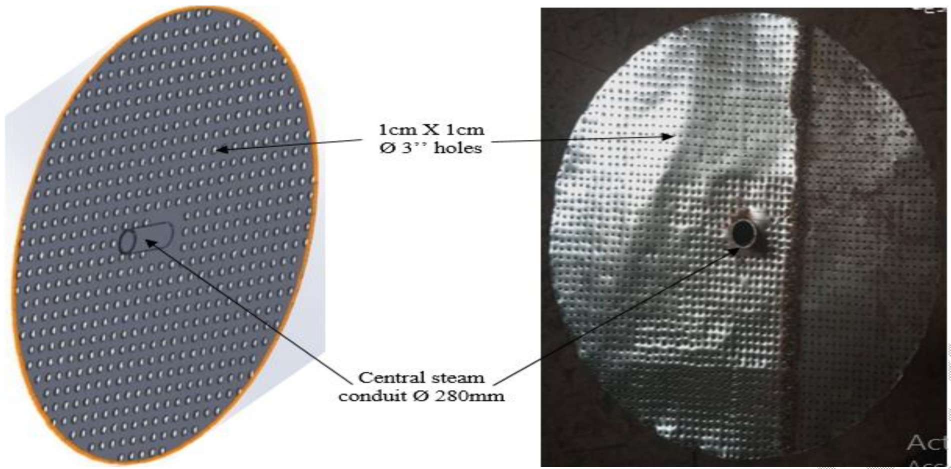


Fig. 8. Perforated false bottom

False bottom (Fig. 8) was perforated and fixed to the wall of the drum by welding. It was lined to divide the drum into its two chambers and to prevent rice from falling to the bottom of the parboiler. Each perforate 3 inches' hole occupies 0.0001 m² surface on the screen, giving a total of the 10569 holes on the false bottom.

3.2.2.3 Tilt Handle and parboiler cover

The tilt handle is attached to be used by the operator of the parboiler to hold and tilt it and discharge the steamed paddy rice from the parboiler. The parboiler cover was used as covered on top of parboiler to protect, prevent lose, escape of the unnecessary steam during the process of soaking and steaming of the paddy rice. It was line with a flat 0.20 m mild steel bar for proper fitting and coverage.

3.2.3 Parboiler stand

3.2.3.1 Stove

The parboiler stand is rectangular shaped with a volume of 0.225 m³. It consists of four legs of 0.45 m height each which is made from 0.03 m × 0.03 m mild steel tube. The parboiler stands on this cube shaped stand with the aid of the frame. The sides of the stove are lined with perforated mild steel sheet to ameliorate the flammability of the wood used during the parboiling process.

3.2.3.2 Frame

Two sites of the cube were constructed with frames in trapezoidal forms and fitted with ball bearings to hold the parboiler in upright position at the base. The frames extend vertically to 0.3 m above the bar to the bearing point where it is fixed to each point to the parboiler to the stand to allow the rotation of parboiler. The parboiler frame is fitted with a door for the putting of wood and removal of wood ash.

3.3 Characteristics of the device for operational efficiency

3.3.1 Parboiled paddy

3.3.1.1 Soaked paddy

Soaking was normally done to achieve quick and uniform water absorption as reported by Wimberly [27]. The average moisture content (water uptake) at different soaking conditions for the three rice parboiling techniques were recorded. Table 3 shows the moisture content at various soaking temperatures.

Table 3. Water uptake of rice after soaking at 70 °C and 90 °C

Soaking	Developed parboiler	Industrial parboiler	Traditional parboiler

time (mins)	weight (g)		weight (g)		weight (g)	
	70°C	90°C	70°C	90°C	70°C	90°C
30	4.9	12.8	7.0	12.5	10.8	20.4
60	5.2	14.0	8.2	16.8	8.2	20.0
90	7.5	15.2	5.0	17.3	7.5	25.0
120	8.0	27.0	7.8	22.0	8.0	24.9

According to Table 3, the moisture absorption increased with increase in the soaking temperature. The effect of soaking temperature on moisture uptake was found significant. The possible reasons for this moisture absorption are explained as follows: (1) Air in the pore spaces of the paddy grain causing resistance to water entry expanded and left the pore spaces with the rise in temperature [28]. This space was quickly replaced by water. Profuse air bubbles were seen to rise during the initial stages of soaking of paddy as reported by Islam et al [29]. (2) Absorption of water by paddy was a diffusion process and depended on the diffusion coefficient which itself increased with the rise in soaking water temperature due to changes in some of the properties of water, such as vapour pressure, viscosity and surface tension as reported by Islam et al [30].

Islam et al [30] reported that the required moisture content for a properly soaked paddy is around 32 to 34%, which was also observed in this study. For the NERICA IR841A rice variety (high amylose content variety) the results indicated that moisture content increased rapidly from an initial value of 13±1% to 33 to 35% after 2½ hrs and 2 hrs at 70 °C and 90 °C of soaking respectively. Since $F_{cal} = 2.2 < F_{tab} = 3.49$, it is concluded that the difference in water uptake of the rice is not significant between the three parboilers. Concerning temperature, Since $F_{cal} = 41.3 > F_{tab} = 4.35$, it is concluded that there is a significant difference in the temperature of the rice using the three parboilers ($P = .05$).

From appearance of the rice kernels that was de-husk manually, it was observed that kernels breakage occurred in samples soaked at 70 °C with high moisture content <33% while samples soaked at 90 °C with moisture content >33% yielded high proportion of head rice.

3.3.1.2 Steamed soaked paddy

Steaming was the most vital and key process to improve the quality of parboiled rice. Utilizing a lid and a false bottom regardless of the shape of containers and volume of paddy for steaming solved the problem of over-cooking. The lid ensured equal heat treatment by maintaining the steam within the parboiler. Thus, by using a lid and a false bottom, the quality of parboiled rice, especially pertaining to discolouration and unevenness of colour, improved. The false bottom separated the water and the wet soaked paddy in the soaking chamber. The water under the false bottom was boiled and it changed into steam by heating the parboiler. The steam passed through the holes of the false bottom and the steam conduit through the mass of paddy above the false bottom. The boiling water was not in direct contact with the soaked paddy and therefore did not deform the grains at the lower portion of the soaking chamber.

In addition, by placing the lid at the mouth of the parboiler, the steam was equally distributed inside the parboiler without leaking out. Therefore, equal heat treatment to each grain was assured and heat energy was also efficiently utilized. The steaming period served as an important factor minimizing discolouration and the broken ratio. There was a trade-off between discolouration and broken ratio in terms of steaming time. Longer applications of steam to the paddy resulted in darker-coloured grains and a lower broken ratio. Shorter applications of steam to the paddy result in lighter-coloured and a higher broken ratio ([6, 11].

3.3.2 Dried and milled paddy

Paddy was dried at a temperature range of 47±1°C for 24 hours on cleaned fryer trays until 14% moisture content. This step was performed because the steamed paddy must be dried immediately after steaming and in particular, moisture in the husk should be removed quickly. The quicker the drying process, the lighter was the colour of the grain [16].

The milling process was done to remove the husk from the paddy as well as the pericarp and embryo from brown rice. Table 4 shows a test on milled rice.

Table 4. Test carried out on milled paddy

Experiment	Sample (kg)
Weight of un-milled rice	50.00
Weight of milled rice	39.37
Weight of whole rice grain	38.68
Weight of broken grains	00.69

3.3.2.1 Milling efficiency

Using equation (4), milling efficiency is 78.74%. This high milling efficiency of the parboiled paddy depended on the better heat treatment given during parboiling and conditions of drying. The severe the heat treatment allows to withstand adverse drying and milling [10,19].

3.3.2.2 Head rice yield

Using equation (5), the head rice yield from this device is 98.22%. This high percentage of head rice yield indicates better processing conditions. Heat treatment improved head rice yield [31]. At a temperature of 90°C soaking, with increase in hydration time, the head rice yield is very encouraging.

3.3.3 Sensory values

The panel assessment tests carried out on the products from the developed parboiler, traditional and industrial parboilers showed a favourable level of rice parboiled using the developed parboiling. According to Table 5, the rice parboiled using the developed and the industrial parboiler have good smell and taste with golden colour. The rice parboiled using the traditional parboiler have bad smell and taste with a dark-yellow colour.

Table 5. Values of the panel subjective tests (Taste, Smell, and Colour)

Developed parboiler			Traditional parboiler			Industrial parboiler		
Smell	Taste	Color	Smell	Taste	Color	Smell	Taste	Color
Very Good	Very Good	Golden yellow	Bad	Bad	Dark brown	Very Good	Very Good	Golden yellow
Very Good	Very Good	Golden yellow	Bad	Bad	Dark brown	Very Good	Very Good	Golden yellow
Very Good	Very Good	Golden yellow	Bad	Bad	Dark brown	Very Good	Very Good	Golden yellow

3.3.4 Cooking quality values

Optimum cooking time, swelling index and water uptake values were determined for unparboiled and parboiled rice by the panelists. Cooking time which was dependent on the rate of water uptake was lower for unparboiled rice than for parboiled samples. It was observed that unparboiled rice took the minimum time of 25 minutes for optimal cooking. The optimal cooking time of parboiled rice samples went up to 33 minutes, which is about 8 minutes longer than for unparboiled rice. The time taken to cook to the same degree of softness was greater for parboiled rice than for the unparboiled rice sample. Parboiled rice cooked into flaky separate and firm grains when compared to unparboiled rice. The golden-yellow colour of the parboiled grains seemed to have reduced on cooking and the cooked rice had creamy to white coloured, almost similar to that of raw rice.

It was observed that unparboiled rice had the minimum swelling index of 0.29, whereas for parboiled samples, the values were higher up to 0.34. This difference depended on the severity of the treatment (parboiling) conditions, the variation being only marginal.

Water uptake of raw rice was recorded to be 2.61 (87%). Due to parboiling, the water uptake value of the parboiled rice sample was 2.25 (75%); it's lower compared to that of unparboiled rice.

3.3.5 Performance of the device

The developed parboiling device was compared to traditional and industrial parboilers. Table 6 shows their characteristics.

Table 6. Parboilers performance

Parameters	Units	Developed parboiler	Traditional parboiler	Industrial parboiler
Mass of paddy rice	ton	0.05	0.05	16
Time taken for soaking	hour	2	18	7
Soaking temperature	°C	90	32	75
Time taken for steaming	hour	0.25	3	0.3
Water/paddy temperature after 10 minutes	°C	87	33	75
Steaming temperature	°C	95	105	90
Quantity of fuel (firewood)	kg	2.5	9.8	-

The developed parboiling device showed that 50 kg of raw paddy was soaked for 120 minutes at 90°C and steamed for 15 minutes at 100°C. During the parboiling test, 2.5 kg of fuel (firewood) was used. Also, 50 kg of paddy was parboiled in 3 hours at 105°C and 9.5 kg of fuel was consumed using the traditional method of parboiling. The time taken and quantity of fuel used to parboil paddy rice using the developed parboiler is low compared to the traditional method of using the conventional drum.

The developed device has an average capacity of 54 tons of parboiled rice per year, compare to 10 tons of parboiled rice per year for traditional device. Using local materials for the construction, the total cost of producing the device which includes material and labour is about USD 160,00. Although local materials were valorized and the device was improved by the stove and the parboiler accessories which most parboiling devices do not have.

4. CONCLUSION

This research project focused on the design, construction and characterization of a rice parboiling system that is cheap, easily affordable to the local processing farmers, easy to maintain and less laborious to use. As the demand for rice increases in many Central Africa countries, local producers look for new innovative systems that can produce competitive high quality rice. Parboiling rice is a food process not only loved by many but also holds many nutritional benefits. The local parboiling device will offer the local community an opportunity to increase the production of rice while minimizing health and environmental effects. The integrated design and construction of the device addressed the post-harvest need for the rice paddy. The functionality of the facility allows users to yield more product by the established sequential work flow. The batches of paddy are parboiled one after the other, maximizing time management and operational efficiency. The stove consumed 29% less wood during the 2½ hours parboiling time. This result favor the overall work flow chain concept of the device. The preliminary characteristics showed that soaking of paddy rice at 90°C for 2 hours and steaming for 15 minutes using the improved parboiling method took a shorter time, no fermentation of the paddy, hence, bad odour did not occur in the milled rice. The percentage head rice yield which was 92.04% and the efficiency of milling was 72.76%. Better parboiling and hence better gelatinization lead to high grain yield and high efficiency of milling and hence good quality of the milled rice. The total cost of producing the device which includes material and labour is about USD 160,00. The developed parboiler is 5.4 times more efficient and 4 times greater in its construction cost than the traditional one. Local materials were valorized and the device was improved by the stove and the parboiler accessories which most parboiling devices do not have.

Therefore, this system can help local farmer in timely processing of paddy and in making effective use of the available good designed and fabricated rice parboiling equipment. This device was found to be easier, faster and better than manual cold soaking and packing of the steamed paddy.

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