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RESEARCH ARTICLE

COOKING ENERGY SAVINGS ACHIEVED WITH AN INSULATED METAL PRESSURE COOKER USING KAPOK WOOL: ECONOMIC AND ENVIRONMENTAL IMPLICATIONS

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ABSTRACT

In order to improve scientific knowledge on this technology to promote its use, we conducted an experimental study of the metal pressure cooker insulated with kapok wool, a biodegradable plant fiber, to determine the energy performance. The equipment allows to finish cooking meals only thanks to the heat stored at the beginning of cooking and to keep the cooked dishes warm for long hours. The experiments carried out on energy savings when cooking some local dishes cooked only in water revealed about 70% savings in butane gas for cooking cowpea and white rice, 38% for cooking oily rice, 75% for pasta and couscous and 30% for cooking potato stew. The average cooking energy saving is around 39%. Finally, we completed these results with a technical, economic and environmental study that showed that a restaurant that adopted a pressure cooker had recouped its investment after only 7 months and made net profits of 131,818 CFA francs during the first year of use. If we consider all the restaurateurs in the city of Ouagadougou, the energy savings made would save approximately 12,691 hectares of forest/year and avoid importing nearly 2,824 tons of butane gas each year. These results demonstrate that this technology can help minimize energy consumption in the restaurant sector.

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INTRODUCTION

In the world, 40% of the population of the poorest countries use 70% of biomass as fuel (1). Biomass occupies on average more than 70% of the energy balances of African countries (2). More than 2.4 billion people use solid biofuels for cooking and heating (3). Projections reveal that the number of people using biomass will reach 2.8 billion in 2030, 82% of whom will be in rural areas (4). In Burkina Faso, a study conducted by Boukary OUEDRAOGO showed that the catering sector is the second largest consumer of energy (wood, coal, etc.) (5). In the search for solutions to save energy in this sector, we have developed a metal pressure cooker insulated with kapok wool. Indeed, plant fibers, which are biodegradable, have proven their effectiveness in terms of thermal insulation (6-7). During the development of the pressure cooker, modeling, simulation and experimental studies have helped to understand the thermo-physical mechanisms of heat conservation inside the pressure cooker (8-10). These studies have also proven that the use of the pressure cooker could lead to huge energy savings. Thus, it is important to clearly highlight the environmental impact linked to the use of such technology in order to feed climate strategies. This is why the objective of this work is to analyze the impact of the use of the pressure cooker on the triple economic, financial and environmental level. To do this, we will first estimate the energy performance of the pressure cooker through an experimental study.

The economic and financial analysis will then be based on the estimation of the return on investment (ROI) time of a pressure cooker and the profits generated by its operation. On the environmental level, we will analyze the quantity of wood saved by a restaurant that operates a pressure cooker compared to a restaurant that does not have one.

MATERIALS AND METHODS

MATERIALS

For this study, we use a metal pressure cooker. The prototype has been designed and technical drawings have been drawn up for its realization. The thickness and density of the kapok wool are respectively 15 cm and 50kg/m^3. For the insulation of the upper part of the pressure cooker, a padded cushion with 15 cm thickness of kapok wool and a 15 mm plywood sheet will be used. The choice of these dimensions is not arbitrary. It corresponds to the situation where the insulation (kapok wool) completely surrounds the size 10 pot. In fact, it is important that there be no air pockets between the insulation and the kettle so as not to accentuate transfers.

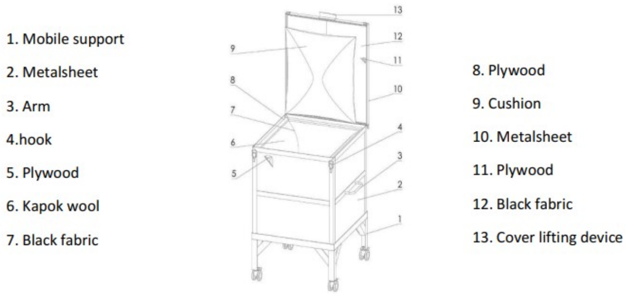

Figure 1. Technical diagram of the pressure cooker

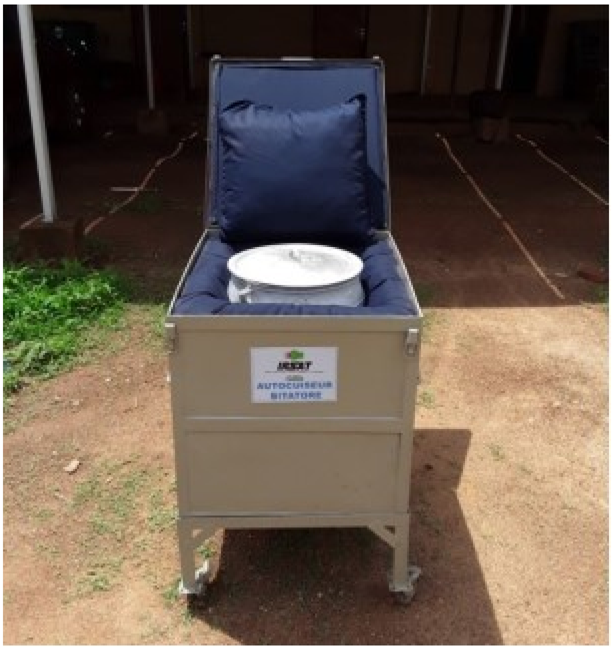

Figure 2. Prototype of a metal model pressure cooker

Kitchen equipment

In addition to the pressure cooker prototype described, we have:

- Two identical classic gas fireplaces connected to two gas bottles of 12.5 kg each,
- Two n°10 pots (capacity 22 liters each),
- Cooking utensils (dishes, kitchen dosers, etc.),
- Food Product,
- A precision balance ± 1g.

Food products

METHODS

Selection of dishes: Before conducting the study, discussions were held with a few restaurants in order to understand their culinary habits. It emerged from these discussions that the commonly cooked dishes are fatty rice, rice sauce, cowpea (with sauce), pasta (with sauce), potato stew and Arabic couscous (with sauce). The quantities chosen are 5kg of products/dishes exceptfor the potato stew (5.5kg of tubers). These quantities were chosen so that the final volume of the different dishes would fit in the No. 10 pots (22 liters). As part of this study, we chose a common sauce (tomato) for the 3 dishes: rice sauce, pasta and couscous. The ingredients chosen for all the dishes are essentially fresh meat and vegetables.

Procedure for preparing food Analysis: The assessment of energy savings for each dish is based on a comparison between the amount of butane gas consumed when preparing the dish entirely on a conventional burner and that consumed when preparing the same dish started on a conventional burner (pre-cooking) and finished with the pressure cooker. In the case of dishes with sauce, the sauce is prepared entirely on the conventional burner. The procedure adopted in each cooking situation (with or without a pressure cooker) was guided by discussions with the stakeholders and the thermal performance of the pressure cooker.

Classic preparation procedure

Product introduction mode: For classic cooking, the products (rice, tubers, cowpeas, pasta and couscous) are introduced after the water has boiled.

Volume of water required per meal: For each given dish, the ratio between the volume of the product (and therefore its mass) and the volume of water to be considered depends on several factors (humidity of the product, cooking time, etc.). Although there are no standard ratios for the dishes used in this study, discussions led to the following ratios:

- For white rice: 1 level volume of rice to 1.3 volumes of water,
- For full-fat rice: 1 level volume of rice to 1.6 volumes of water,
- For cowpea: 1 level volume of cowpea to 1.4 volumes of water,
- For potato stew: 1 level volume of potatoes to 1.6 volumes of water,
- For pasta: 1 level volume of pasta to 1 volume of water,
- For couscous: 1 level volume of couscous to 0.8 volumes of water. Thus, for each product, we determined its density in order to calculate the volume of water required for cooking it. The results are shown in Table 1.

Table 1. Estimation of the volume of water required per meal using a conventional stove

Food products	Quantity (kg)	Density (kg/l)	Calculated volume of water required l)	Required volume of water retained (l)
Rice	5	0,9	7,22	7
Fat rice	5	0,9	8.88	9
Cowpeas	5	0,85	8,23	8
Potatoes	5,5	1	8,8	9
Pasta	5	0,78	6,41	6
Couscous	5	0,8	5	5

Preparation procedure with the pressure cooker Product introduction mode: In the case of cooking with the pressure cooker, given the thermal performance of the pressure cooker previously indicated, it is not necessary to wait for the water to boil before introducing the products. Apart from fatty rice and potato stew which require good cooking of the ingredients, especially meat, dishes such as white rice, cowpeas, pasta and couscous are introduced as soon as the water acquires sufficient thermal inertia, which is the case as soon as the first bubbles appear.

Volume of water required per meal: The volume of water required for cooking dishes with a pressure cooker differs from that of conventional cooking. In fact, it is necessary to take into account the very significant evaporation of water during conventional cooking, whereas in the case of cooking with a pressure cooker, there is practically no evaporation of water. Experiments were conducted to estimate this quantity of water evaporated per dish in order to adapt the volumes of water used in conventional cooking to cooking with a pressure cooker. The results obtained made it possible to retain the values indicated in Table 2.

Table 2. Estimation of the volume of water required per dish with the pressure cooker

Food	Quantity (kg)	Volume of water required for classic cooking (l)	Volume of water required with the pressure cooker (l)
White rice	5	7	5
Fat rice	5	9	7
Cowpeas	5	8	6
Potatoes	5,5	9	7
Pasta	5	6	4
Couscous	5	5	3

Experimental protocol: For each dish (white rice, full-fat rice, potato stew, cowpea, pasta and couscous), an entire cooking is carried out on the conventional burner and the mass of butane gas (M_1) consumed is noted at the end of cooking. At the same time, another cooking of the same dish (same quantity of products and ingredients) is started on another conventional burner, then stopped at a given time to be finished by the pressure cooker. The mass of butane gas (M_2) consumed in this pre-cooking phase is also noted. The saving in mass of butane gas (EE) is then given as a percentage by the relationship (1):

$$EE=(M_1-M_2)/M_1)\times 100 \quad (1)$$

The calculation uncertainty on EE is given by the expression:

$$\frac{\Delta EE}{EE} = \left(\frac{\Delta M_1 + \Delta M_2}{M_1 - M_2} + \frac{\Delta M_1}{M_1}\right) \quad (2)$$

For dishes requiring a sauce (white rice, cowpeas, pasta and couscous), the sauce is prepared entirely on the conventional burner. The mass of gas consumed during this cooking (Ms) is noted. The saving in mass of butane gas (EE') for these dishes with their sauces is then given as a percentage by the relation (3):

$$EE'=((M_1-M_2)/(M_1+Ms))\times 100 \quad (3)$$

The calculation uncertainty on EE' is given by the expression:

$$\frac{\Delta EE'}{EE'} = \left(\frac{\Delta M_1 + \Delta M_2}{M_1 - M_2} + \frac{\Delta M_1 + \Delta M_s}{M_1 + M_s}\right) \quad (4)$$

RESULTS

Energy saving analysis: The butane gas savings for cooking dishes are summarized in Table 3.

Analysis of the table 3 shows that in a conventional kitchen, the dish that consumes the most energy is cowpea, with 1.4 kg of gas consumed for 5 kg of products. This is followed by white rice (1 kg), pasta (0.9 kg) and couscous (0.6 kg) for the same quantities of products. The results also show that cooking food (only in water) with the pressure cooker results in significant energy savings (70-75%). These results are mainly due to the good energy performance of the pressure cooker but also to the cooking protocols used in both cases (with and without pressure cooker) which minimise pre-cooking times compared to the cooking time of a conventional kitchen. In fact, with the pressure cooker, the products are introduced well before the water boils, which considerably reduces energy consumption. In fact, when boiling is reached, the latent heat of evaporation of the water (about 2260 KJ/kg) is very high, which considerably increases energy consumption. It should also be noted that during conventional cooking, untimely opening of the kettle, convective and radiative losses due to the fact that the kettle is exposed to the open air are also factors that increase energy consumption.

For cooking fatty rice and potato stew, the energy savings are 38% and 30% respectively. Although these values are interesting, they are lower than those calculated above. This is due to the fact that for the fatty rice and potato stew, the pre-cooking takes into account the cooking of the ingredients, which takes a long time and reaches boiling point so that the meat is well cooked. Although the amount of water is also reduced in comparison to conventional cooking, the fact that pre-cooking reaches the boil necessarily results in high energy consumption. When taking into account the preparation of the sauce for the above dishes, the new energy savings for these dishes are shown in Table 4. Table 4 shows that when taking into account the preparation of the sauce, the energy savings drop dramatically (28-48%). These results are explained by the fact that the pressure cooker does not allow sauces to be prepared. Thus, the amount of energy consumed during the preparation of the sauce is the same in both cooking cases (with and without a pressure cooker), which causes the energy savings to drop. For cooking oily rice and tuber stew, the energy savings are reported in Table 5. Although these two dishes have the same cooking time on the conventional stove, the energy consumption for the potato stew is slightly lower than that of the oily rice because the gas flow rate has been slightly reduced to take into account the malleability of the tubers. As for the previous dishes, the results obtained show that cooking oily rice and the tuber stew with the pressure cooker results in energy savings (30-38%). These energy savings, although interesting, are significantly lower than those obtained with cooking dishes only with water (white rice, cowpeas, pasta and couscous). Indeed, for oily rice and the tuber stew, pre-cooking takes into account the cooking of the ingredients which takes a lot of time and reaches boiling point so that the meat is well cooked.

Table 3. Energy savings achieved with the pressure cooker

Dishes	White rice	Fattyrice	cowpea	potatostew	Pasta	Couscous
Mass of food products (kg) for each cooking	5	5	5	5.5	5	5
Normal cooking duration with a conventional fireplace	1h10	1h45mn	2h	1h45	1h	45mn
Precooking duration with a conventional fireplace	20 mn	1h	45mn	1h15 mn	15 mn	10 mn
Minimum duration of cooking in the pressure cooker	1h	45 mn	4h	1h	45 mn	30 mn
M1(kg)	1	1,3	1,4	1	0,9	0,6
M2(kg)	0,3	0,8	0,42	0,7	0,22	0,15
Energy saving (%)	**70 ± 0.38**	**38 ± 0.48**	**70 ± 0.27**	**30± 0.76**	**75 ± 0.40**	**75 ± 0.61**

Table 4. Energy savings for dishes with sauce

Food	White rice (+ sauce)	Cowpea (+ sauce)	Pasta (+ sauce)	Arabic couscous (+ sauce)
Duration of cooking the sauce	1h10	50 mn	1h10	1h10
M1 (kg)	1	1,4	0,9	0,6
M2 (kg)	0,3	0,4	0,22	0,15
Ms (kg)	1	0,7	1	1
Energy saving (%)	**35 ± 0.38**	**48 ± 0.29**	**36 ± 0.39**	**28 ± 0.56**

Although the quantities of water are also reduced compared to conventional cooking, the fact that pre-cooking reaches boiling necessarily involves a high energy consumption, as previously explained, which results in less significant energy savings.

Average energy saving of the pressure cooker: Cooking experiments conducted on a set of 6 local dishes, namely rice sauce, fat rice, cowpea (with sauce), potato stew, pasta (with sauce) and couscous (with sauce) showed respectively gross energy savings of 35%, 38%, 48%, 30%, 36% and 28% obtained following a well-given protocol. In the continuation of our investigations, an average value of these energy savings is necessary. To estimate this average value, it is important to take into account the weight linked to each dish in the culinary habits of restaurants. However, these dishes do not have the same importance in restaurant menus. Some dishes are favored over others. In the literature, there is no scientific data to estimate these weights, which is why we make the following assumptions:

- Fatty rice, rice sauce and cowpea are the most cooked dishes and have the same weight in the restaurant's culinary habits,
- Pasta is the medium-cooked dish,
- Potato stew and couscous are the least cooked and have the same weight.

According to Table 6, the average energy saving of the pressure cooker is around 39%.

Economic, financial and environmental impacts: In order to carry out the economic, financial and environmental analysis of the use of the pressure cooker, we study the case of two restaurants, one of which has a pressure cooker while the other does not. We then formulate some hypotheses to facilitate the study.

Hypotheses

Both restaurants strictly apply the protocols established in this study when preparing their dishes

- The pressure cooker prototype is the one developed in this study,
- The average energy performance of the pressure cooker remains unchanged when using wood as fuel,
-
- Both restaurants operate all year round 365 days a year and each consume wood and butane gas,
- The energy consumption data for the restaurants are those of the survey conducted by APEX-PREDAS in 2004 which indicates that a restaurant in Ouagadougou consumes on average 21 kg of wood and 2.5 kg of butane gas per day (11),
- The prices per kilogram of wood and butane gas are 50 CFA and 400 CFA respectively.
- A cubic meter of wood weighs 0.25 tonnes (12),
- Considering the hybrid scenario, the average level of forest exploitation in Burkina Faso is 7.72 cubic meters/ha/year (13),
- The number of restaurants in Ouagadougou is 7932 according to INSD statistics from 2001-2002 (14).

Investment: Based on the developed prototype, the investment of the restaurant purchasing a pressure cooker is detailed in Table 7 below. The amount that the restaurant will have to pay is therefore 160,000 FCFA

Equivalence: 1 Euro=655 FCFA and 1 USD=590 FCFA

Economic, financial and environmental impact: Based on the assumptions made and the investment cost, the economic, financial and environmental impact of using the pressure cooker are reported in Table 8. The payback time is calculated using the following formula:

$$ROI = \frac{\text{Cost of investment}}{\text{Investment gain}} \quad (5)$$

The results obtained show that the use of the pressure cooker over the course of a year by a restaurant leads to savings of 2,989 kg of wood, or 12 cubic meters of wood, which corresponds to 1.6 ha of forest preserved per year. As for the butane gas saved, it is of the order of 356 kg, or approximately 29 gas bottles of 12.5 kg each. This quantity of butane gas also corresponds to net reductions in imports, therefore favorable to the national economy. Energy savings lead to financial savings of the order of 291,818 FCFA/year. The investment is amortized in 7 months and the restaurant makes a net profit of 131,818 FCFA during the first year. These figures concern only one restaurant that uses a pressure cooker. If we consider that all the restaurants in the city of Ouagadougou each use a pressure cooker, the economic and environmental impacts become considerable.

In fact, this hypothesis would lead to 12,691 ha of forest preserved per year and the saving of nearly 2,824 ton of butane gas/year.

CONCLUSION

In this work, we conducted an energy, technical-economic and environmental study of the pressure cooker prototype developed as part of this study. We first estimated the energy savings of cooking some local dishes (rice, cowpea, potato stew, pasta and couscous) through an experimental study and based on well-given cooking protocols. This study showed that the use of the pressure cooker allows energy savings of between 30 and 48% compared to conventional cooking techniques. Taking into account the culinary habits of restaurants and based on assumptions, we finally obtain an average energy saving of 39%. This data then allowed, based on calculation assumptions, to evaluate the economic, financial and environmental impact of the use of a pressure cooker by a restaurant compared to a restaurant that does not have one. The results obtained show that a restaurant that invests in the purchase of a pressure cooker, amortizes its investment in only 7 months, generates financial savings of around 291,818 FCFA/year and makes net profits of 131,818 FCFA during a yearof use. The savings in wood made make it possible to save around 1.6 ha of forest/year and reduce the import of nearly 356 kg of butane gas/year. If all the restaurants in the city of Ouagadougou each adopt this technology, this would make it possible to save 12,691 ha of forest/year and reduce the import of nearly 2,824 tons of butane gas/year.

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Nomenclature

FCFA: African Financial Community
h: Hours
M_1: Quantity of energy consumed with the conventional fireplace (kg)
M_2: Quantity of energy consumed with the pressure cooker (kg)
ΔM_1: Absolute uncertainty on M_1 (kg)
ΔM_2: Absolute uncertainty on M_2 (kg)
ΔEE: Absolute uncertainty on EE (%)
ROI: Return on investment

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