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Performance Study of a Developed Automated Cooking System

I. T. Ucheoma[1*], K. O. Chilakpu[1], N. R. Nwakuba[1] and N. C. Ezeanya[1]

[1]*Department of Agricultural and Bioresources Engineering, Federal University of Technology, Owerri, Nigeria.*

Authors' contributions

This work was carried out in collaboration among all authors. All authors read and approved the final manuscript.

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ABSTRACT

Aims: To identify the heat energy, timing along with other cooking parameters required for cooking rice, beans, okra and yam using the gas, electric and automated cooker respectively.
Study Design: The studied automated cooking system was digitally calibrated to ensure the best operation of the various receptacles for adding ingredients such as the cylindrical dispenser, reciprocating dispenser besides the precision fluid dispensing unit synchronized with the automatic opening and closing of the receiver lid (Pot).
Place and Duration of Study: Department of Agricultural and Bioresources Engineering, Federal University of Technology Owerri, Nigeria, between October 2018 and November 2019.
Methodology: The performance evaluation of the automated cooking system was done after the selected food samples (rice, beans, yam and okra) were cooked manually with the electric and gas cookers respectively. The major cooking parameters measured and analyzed were the volume of water used, quantity of food and ingredients, temperatures and heating energies of the cooking systems, overall cooking time for food samples and the time for adding ingredients and water into the food being cooked.
Results: The experimental results show that the cooking time required to prepare 200 g of the studied food samples namely; rice, beans, yam and okra soup using the electric cooker, gas cooker and the automated cooker were; 50 mins, 69 mins, 30 mins, and 17 mins (for electric

**Corresponding author: Email: ihuomachuwu@gmail.com;*

cooker); 51 mins, 72 mins, 34 mins and 19 mins (for gas cooker); 45 mins, 64 mins, 25 mins and 14 mins (for automated cooker) respectively. The heating energy data computed for the food samples were: 199 kJ, 416.72 kJ, 182.2 kJ and 516 kJ for okra, beans, yam and rice using the automated system. It was revealed that the thermal efficiencies of the automated cooking system is higher than the thermal efficiencies of other cooking system (electric and gas cookers). The adiabatic nature of the enclosed automated system makes cooking more hygienic and faster due to increased heat energy utilization. Model equations were derived for predicting the heating energy and time required for cooking and to soften these food samples using gas cookers, electric cookers and in subsequent automated cookers. The cooking information obtained from the experiments streamlines a generic recipe and the requirements for cooking different foods with the auto-cooker and has greatly simplified the process of cooking.

Conclusion: The automated cooking system offers a significant benefit to the users who have time limitations. The findings from this work may be applied for the commercial production of automated cookers as prospect of modification and further studies could be explored.

Keywords: Automated cooker; food; electric; gas; time; heating energy.

NOMENCLATURES

$MC_{dt}dT$	*: Rate of increase of thermal energy (W)*
$Qcond,in$	*: Net energy conducted (W)*
$Qrad,in$	*: Net energy radiated (W)*
T_{ref}	*: Reference temperature (˚C)*
$T0$	*: Average surface temperature (˚C)*
h	*: Heat transfer coefficient (W/m^2˚C)*
A	*: Area available for convective heat transfer (m^2)*
X	*: Mass fraction of ingredients (g).*
Q	*: Heat energy (J)*
M	*: Mass of food material (kg)*
C	*: Specific heat capacity of material (J/kg)*
ΔT	*: Temperature difference (˚C).*
X'	*: Time (mins) for cooking food samples (rice, beans, yam, okra),*
Y'	*: Heat energy (J) for cooking systems (electric, gas, auto-cooker)*

1. INTRODUCTION

Food is an essential part of life. It gives the required energy and body nutrients to grow and develop, to be healthy and active to move, work, play, think and learn [1]. It is a known fact that all animals eat, but only human beings cook their foods amongst all the animals. So cooking becomes more than necessary as it is the symbol of our humanity and what marks us off from the rest of nature [2]. Cooking primarily means the addition of heat to soften food for human consumption. A lot of cooking methods are used and practiced by different races, tribes, cultures, in catering and hotel industries etc. Each has its peculiar merits and demerits, as a result of different people. Various recipes and techniques for all kinds of food substances have been developed at different times. Cooking food in a liquid (water, bouillon, stock, milk) is known as Boiling. Examples of food which might be cooked by boiling are; stocks (beef, mutton, chicken), sauces, glazes, soup, farinaceous, fish and vegetables. Poaching is a cooking technique that involves submerging of food in liquid such as water, milk, stock or wine [3]. Stewing is a long, slow cooking method where food is cut into pieces and cooked in the minimum amount of liquid, water, stock or sauce [4]. Braising is a method of cooking food in the oven by steam (moist heat) under varying degrees of pressure [5,6]. Cooking food by dry heat in an oven is known as baking [7,8]. Roasting is cooking in dry heat in an oven or on a spit with the aid of fat or oil [9]. Frying is an oil based cooking technique used to prepare portion sized cuts of meat, fish and fritters. Grilling is a fast method of cooking by radiant heat, [10,11]. These cooking methods are critical to the development of suitable cooking facilities. Over the years several heating devices have been employed in easing these methods of cooking. Heating in this context refers to the increment of the temperature of a body which can be achieved in different forms viz; conduction, radiation and convection. Usually, heating by conduction remains the most effective method used in the preparation of food because there is a direct transfer of heat from one medium (cooker) to another (pot containing food materials). Consequently, these heating devices bring about a steady state incremental cooking temperature sufficient to get the food done within a specified time [12]. Some common methods of cooking technology includes the use of charcoal fire cooking, kerosene stove, gas cooking, electric cooking and solar cooking technologies [13]. The importance of cooked food can never be over emphasized, hence, thousands of people spend their time in the kitchen preparing food.

Recently, the introduction of automation has improved the age long practice of cooking. Automatic cooking machines are designed to reduce the arduous procedure involved in food preparation. The automated rice cooking machine is one of the electrically operated cooker that has similar features with the automated cooking system examined in this study. It is a machine which automatically cooks the required dish by the press of a button [14]. Some of the common components found in automated cookers are; the LCD indicator, cooking mode, AC power supply, induction heater and output pot. Electric rice cookers automate the process by mechanically or electrically controlling heat and timing, thus freeing up a heating element on the cooking range that had to be otherwise occupied for rice cooking [15]. Although the rice cookers do not necessarily speed up the cooking process, the automated rice cookers are typically used for the preparation of plain or lightly seasoned rice. And this makes the rice cooker unsuitable for handling other foods apart from rice. The M-cooker developed by Somarathna R [16] is a fully automated cooking system, which can be controlled via the mobile input of the user. The user's physical presence is not required to operate the system. The ingredients are pre-fed toingredient containers and could be automatically added by the system to the cooker upon the command of the user with a number of servings (up to three servings at once). Although the system itself measures the quantity and adds the ingredients as required, Somarathna R [16] report did not capture the technical performance of the M-cooker with respect to certain recipes and cooking parameters. The Programmable Logic Control based automatic cooking machine by Kumbhar VB et al. [17] has the conveyor mechanisms, tilting mechanisms, lid mechanism, pan shaking and dumping mechanism and auto-gas igniter mechanism. It was found that the inbuilt Human Machine Interface (HMI) makes its operation easy. However, the absence of water or fluid dispensing unit in the machine limits the cooking to a few recipes. The literature review by Singh S et al. [18] represents the summary of different types of dishes prepared by different robots. They investigated some missing data which could enhance cooking performances such as; dishes temperature, how much temperature the robot or material of the robot can bear the heat even at high flame. However, their experimental survey focused on developing optimum cooking robot for preparing India dishes. The automated cooking machine developed by Kumar A et al. [19] has a combination of electrical and mechanical features similar to the understudied automated cooking system. These components include; the bowl, liquid containers, stirrer, induction cooker, spice dispenser, cooking pot integrated with HMI. This user friendly set-up ensures the preparation of quality food with less supervision. Agreeably, their machine configuration is fashioned to handle Indian recipes ranging from the Jaika India, Maggi, Kadhai and Chilly Paneer which are different for cooking Nigerian staple food such as Okra soup, beans and pottage yam, prepared with the automated cooking system.

Furthermore, this research work was necessitated by the demand for enhanced food recipes and the need to improve the inconveniences involved in the manual and automated cooking procedures. The essence of undertaking this research work is to study the technical performance of the automated cooking system by identifying the heat energy, timing and other cooking parameters required for cooking rice, beans, okra and yam using the gas, electric and automated cooker respectively. The introduction of digitally controlled 16x2 LED screen, enhanced by a 4x4 matrix keypad in the automated cooker is expected to limit the time spent in cooking using precision monitoring and controlled dispensing of ingredients inside a hygienic system. The automated cooker ensures the quality of food cooked in record time and to offer a guide for the improvement of the existing cooking machinery.

2. MATERIALS AND METHODS

In the design of food making machines, adequate information on manual food processing is required Ajav EA et al. [20]. The automated cooker was designed with an Arduino software to ensure the operation of the various receptacles for adding ingredients (cylindrical dispenser, reciprocating dispenser), the lid opener and the precision fluid dispensing unit illustrated in Fig. 1. Based on the machine functionality, an experimental procedure was outlined in tandem with the American Society of Agricultural Engineering Standard [13], aimed at achieving the following;

a. Defining the cooking parameters for the selected food samples and to ensure their cooking requirements especially for evaluating the automated cookers as well as for manual cooking methods.
b. Evaluate the components and operations of the automated cookers over manually cooking with gas cooker and electric heater.
c. Provide a common format for presentation, determination and interpretation of cooking parameters to facilitate communication using a model equation.
d. Provide unified measure of performance that may be considered by consumers and to determine a guideline for improved designs of automated cookers.

2.1 Sample Preparation

From the design specifications of the automated cooker, the recommended food materials that can be prepared with it are mostly moisture-laden food materials with high thermal conductivity, thermal diffusivity and high specific heat, [21]. Consequently, the selection of staple food that are manually cooked was considered as the top priority. The chosen food samples were: rice, beans, yam and okra soup. Before the testing of the automated cooker, the chosen food samples were measured averagely (200g per food sample) with a 5 kg kitchen weighing balance. The samples were washed and cooked manually using gas and electric heater respectively. A few ingredients ranging from salt, pepper, onions and other spices were measured and added distinctly to the food during the cooking process. A graduated plastic container (max. vol. of 3 liters) was used to measure the volume of water that was added to cooked food samples at intervals. And a stopwatch was equally used to record the overall cooking time including the time for adding water and ingredients into the food. A kitchen thermometer (0 - 300°C range) was used to measure the temperature readings recorded in Table 1. during the cooking operations.

2.2 Experimental Procedure

The automated cooker was calibrated to ensure that the digitally controlled components such as the ingredient dispensers, motorized lid opener and the fluid dispenser were functioning with precision. Afterwards, the same quantity of food samples, ingredients and volume of water were loaded and cooked with the automated cooking system at the Federal University of Technology Owerri, (FUTO). The automated cooker displayedin Fig. 2. was used to prepare the selected food samples with the same quantity of ingredients combination.

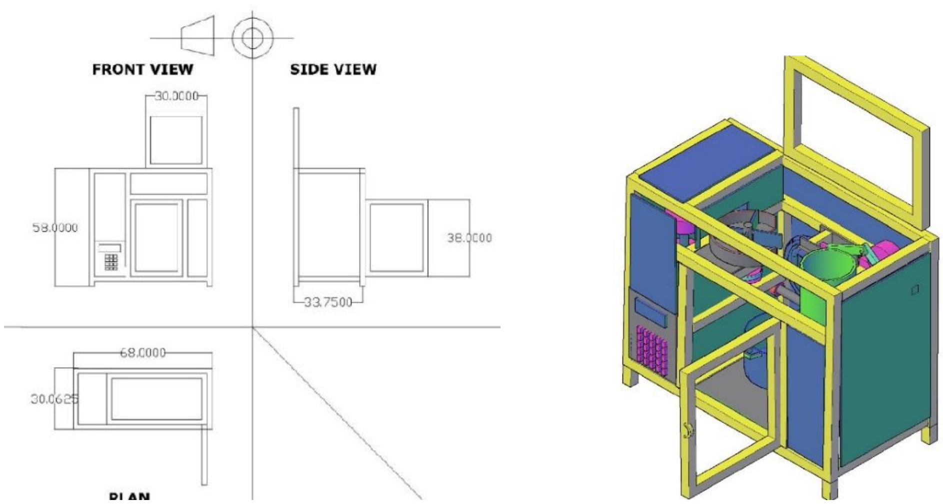

Fig. 1. Orthographic and pictorial view of the automated cooker

Table 1. Measured temperature readings from the cooking systems

Temperature/System	Gas Cooker	Electric Cooker	Automated Cooker
Initial Temperature (˚C)	33	32	32
Final Temperature (˚C)	96	99	112
Temperature difference(˚C)	63	67	80

Note: initial temperature = ambient temperature

Fig. 2. Pictorial view of the developed automated cooking device

The quantity of ingredients used for different food samples were varied accordingly, while the quantity of food for each food sample was 200 g. The recipes include; the ingredients and the volume of water required for cooking each food sample. The proper timing for adding the ingredients and water into the food were recorded at intervals. Fig. 3. depicts the pottage beans cooked with the automated cooker. The machine was also used to prepare the joll of rice shown in Fig. 4. and the okra soup presented in Fig. 5. While Fig. 6. is a sample of the yam cooked with the automated cooking system.

Fig. 3. Cooked beans pottage

Fig. 4. Cooked jollof rice

Fig. 5. Cooked yam

Fig. 6. Cooked okra soup

The specific heat capacities of the food samples were obtained and used to compute the heating energies for the cooking systems using Equation (1) [22].

$$Q = MC\Delta T \quad (1)$$

The mass of the ingredients were considered since they are usually grouped in classes (salts, carbohydrates and other ingredients). And these classes characterize the food mixtures. Hence, the specific heat capacities (Cp) of the mixtures were calculated using Equation (2) [23].

$$Cp = 4186(0.2X_{salt} + 0.34\, X_{vegetable} + 0.37X_{spices} + 0.4X_{pepper}) \quad (2)$$

The cooking thermal efficiency (η_c) was calculated using Equation (3) as reported by Dunu CI et al. [24]:

$$\eta_c = \frac{\text{Rate of heat dissipated (J/hr)}}{\text{Power input (kW)}} \quad (3)$$

The thermal equations given by Dunu CI et al. [24] were used to determine the heat generated from the system as stated in Equation (4):

$$hA(\ 0 - Tref\ ) = Q + Qrad{,}in + Qcond{,}in - MCdtdT \quad (4)$$

The underlying polynomial expressions were obtained from the plot between the heating energy versus the time for cooking the food samples in different cooking systems. Equation (5) can used to find the cooking time for rice in different systems;

$$Y = 28866x^2 - 170169x + 657966 \quad (5)$$

The models developed in Equation (6) can be used to determine the time for cooking beans with different cooking systems;

$$Y = 23416x^2 - 137892x + 531199 \quad (6)$$

The appropriate model for predicting the heating energy and time for cooking okra soup was found using Equation (7)

$$Y = 11174x^2 - 65803x + 253676 \quad (7)$$

The cooking time for yam can be computed using Equation (8);

$$Y = 10231x^2 - 60251x + 232215 \quad (8)$$

3. RESULTS AND DISCUSSION

The information presented in Tables 2-4 shows the technical performance of the heat sources (electric, gas and automated cooker). Table 2 gives the appropriate data for determining the average cooking time of the selected food samples and the time for adding ingredients and water into the food cooked with the electric cooker. The adjoining data reported in Table 3 shows the cooking parameters obtained by using a gas cooker, while Table 4 is the result of the cooking experiments performed with the automated cooker. The cooking information gotten from the systems studied (automated, electric and gas cookers) shows the time range for rice gelatinization. It is one of the methods used to confirm when the food (rice) is done and ready for consumption, because the starch granules absorbs water and swell in size [25]. More so, Table 4 shows that the time for cooking rice with an automated cooker is 45 minutes which is time efficient when compared to the time used for cooking rice manually with gas and electric cookers which are 51 and 50 minutes respectively.

3.1 Heat Source Performance

The outcomes of Table 4 show that the automated cooker cooks food faster than the electric and gas cookers. The confined chamber of the automated cooker makes it a better adiabatic system when compared to the electric and gas cookers. Besides the major source of heat being electricity, other sources of heat which may be considered passive contribute to the total heat supply of the system. The other heat sources include; heat reflected back into the system as a result of heat conduction and the radiation from the interior lining (stainless sheet) of the body frame. The heat equations were modified as expressed in Equation (4) [24]. It was observed that, as the ambient environment gets hotter, the faster, the mass fraction (including the ingredients) of the food materials will heat up. This explains why the cooking of rice requires the highest form of energy due to its greater water volume and mass of food materials. Correspondingly, cooking yam requires the least energy due its associated mass fraction when compared to okra. Deductively, okra soup with the total water volume of 55cl had the lowest cooking time (at constant mass with different systems) because of its high specific heat capacity. Beans has the highest cooking time due its low specific heat capacity. Hence, it requires a lot of time to cook food with low specific heat capacity. Sufficiently, cooking with an automated cooker enhances the temperature gradient of food materials.

3.2 Heating Energy Requirements

The heating energies of food samples (Q) recorded in Tables 5, Table A1-A2 (in Appendix) were computed using Equations. (1) and (2). The cooking thermal efficiencies (E) were calculated using Equation (3) as reported by Dunu CI et al. [24].

3.3 Heat Energy Required for Rice Doneness

A model was developed to show the heat energy and time relation for cooking rice in different systems using in Equation (5). The heat energy computed for cooking rice in Table 5 corresponds to the numerical measure reported by Dilip KD et al. [26] for cooking rice. Their experiments which determined the minimum heat (Qm = 562 kJ) required in cooking 1 kg of dry rice using the new method of cooking and the sensible heat (ht = 465 kJ) tallies with the data found in Table 5. Similarly, these findings revealed that heating properties (i.e.,Qm, ht) also depend on quantity of water used. In the determination of these quantities, it was confirmed that 1.5 liters of water could soften rice (between 0.2 kg to 1 kg) during cooking. When 1.2 liters of water is used with 1 kg of dry rice, the cooked rice is hard. Thus, the volume of water can be adjusted between 1.2 to 1.6 liters per kg of rice when using an automated cooker, depending on the taste of the consumer. The results obtained from Tables 2-4 are comparable to the range of time (20 minutes to 1 hour) required for most electric rice cookers to complete cooking [15]. It was found that the time needed for cooking rice depends on the quantity of rice (grams), the power of heating element and atmospheric pressure, which are variable. The outcome of Table 4 also showed that the heat energy essential for cooking 200 g of dry rice is greater than the energy used to cook other food samples (beans, yam, okra), although it takes a longer time to cook beans than it is to cook rice. By extension, it could be inferred that the specific heat capacity of a food material besides the volume of water used for its cooking, influences the quantity of heat energy that is required to get food done. Fig. 7 confirmed that the higher, the heat energy, the faster the time for cooking rice.

3.4 Heat Energy Required for Beans Maillard Reaction

Beans undergo three major phases when it is cooked. First, the change in protein molecule structure as a result of denaturing when heat is applied to it. Second, there is a maillard reaction when beans is combined with carbohydrate molecule during cooking which results in browning and flavor changes. While hydration occurs in the third stage [25]. Currently, the cooking time for beans is experimentally measured using automated mattson pin drop

[27]. In other words, it is the time for 80% of seeds to be completely pierced by a 2mm stainless pin during heating in water. However, [28] argued that beans cooked without presoaking takes a longer time due to simultaneous hydration. Similarly, [29] predicted a model for the cooking time (ranging from 80 to 147 minutes) of unsoaked beans using hyper-spectral imaging technology after considering the cooking methods, growing environment and storage conditions. Interestingly, these findings can be used with the automated cooker since it is digitally controlled. The results obtained from Tables 2 and 3 were used to determine the prediction time and volume or water required for cooking beans with the automated cooker and it matches with the beans quantification data (1 cup of beans = 3 liters) captured in the work of [30]. The automated cooking system achieves the maillard reaction of beans with 416.7 kJ in 64 minutes which is time efficient when compared to the time actualized with the gas and electric cookers as shown in Fig. 8. This is traceable to the heat energy generated in the system. The models developed in Equation (6) determines the time for cooking beans with different cooking systems:

Table 2. Manual cooking information for electric heater

Cooking parameters	Rice (200 g)	Beans (200 g)	Yam (200 g)	Okra soup (200 g)
Ing-1; Salt	20 g	20 g	20 g	20 g
Ing-2; Pepper	25 g	20 g	30 g	40 g
Ing-3; Spices	80 g	30 g	60 g	50 g
Ing-4; Vegetables	90 g	60 g	90 g	150 g
Total mass of food	415 g	330 g	400 g	460 g
Initial water vol. (cl)	50	50	50	30
Quantity of water added/interval round 1 (cl/mins)	50cl/18 min	50cl/19 min		10cl/5 mins
Quantity of water added/interval round 2 (cl/mins)	50/37 mins	50/52 mins		5cl/8 mins
Quantity of water added/interval round 3 (cl/mins)				10cl/11 mins
No of water rounds	2	2		3
Total water vol. (cl)	150	120	50	55
Total cooking time (min)	50	69	30	17

Ing.= Ingredients

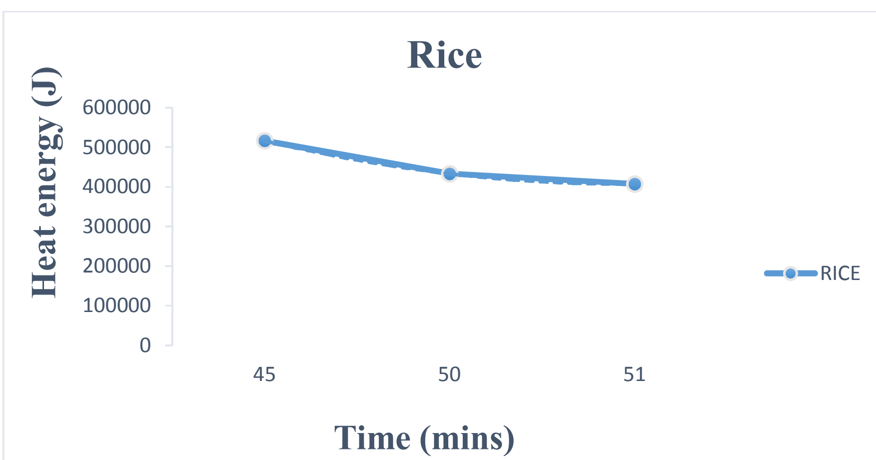

Fig. 7. Rice cooking energy versus time graph

Table 3. Manual cooking information for gas cooker

Cooking parameters	Rice (200 g)	Beans (200 g)	Yam (200 g)	Okra soup (200 g)
Ing-1; Salt	20 g	20 g	20 g	20 g
Ing-2; Pepper	25 g	20 g	30 g	40 g
Ing-3; Spices	80 g	30 g	60 g	50 g
Ing-4; Vegetables	90 g	60 g	90 g	150 g
Total mass of food	415 g	330 g	400 g	460 g
Initial water vol. (cl)	50	50	50	30
Quantity of water added/interval round 1 (cl/mins)	50cl/18 min	50cl/19 min		10cl/5 mins
Quantity of water added/interval round 2 (cl/mins)	50/37 mins	50/52mins		5cl/8 mins
Quantity of water added/interval round 3 (cl/mins)				10cl/11 mins
No of water rounds	2	2		3
Total water vol. (cl)	150	120	50	55
Total cooking time (min)	51	72	34	19

Ing = Ingredients

Table 4. Automatic cooking machine information

Cooking parameters	Rice (200 g)	Beans (200 g)	Yam (200 g)	Okra soup (200 g)
Ing-1; Salt	20 g	20 g	20 g	20 g
Ing-2; Pepper	25 g	20 g	30 g	40 g
Ing-3; Spices	80 g	30 g	60 g	50 g
Ing-4; Vegetables	90 g	60 g	90 g	150 g
Total mass of food	415 g	330 g	400 g	460 g
Initial water vol. (cl)	50	50	50	30
Quantity of water added/interval round 1 (cl/mins)	50cl/18 min	50cl/19 min		10cl/5 mins
Quantity of water added/interval round 2 (cl/mins)	50/37 mins	50/52 mins		5cl/8 mins
Quantity of water added/interval round 3 (cl/mins)				10cl/11 mins
No of water rounds	2	2		3
Total water vol. (cl)	150	120	50	55
Total cooking time (min)	45	64	25	14

Ing = Ingredients

Table 5. Heat energy requirements for automated cooker

Food / C_p	Heat energy (kJ)	Cooking efficiency (E)
Okra (3.81 J/kg)	199.04	34
Beans (1.17 J/kg)	416.72	73
Yam (3.27 J/kg)	182.19	32
Rice (1.52 J/kg)	516.66	91

Note; C_p= specific heat capacity [19]

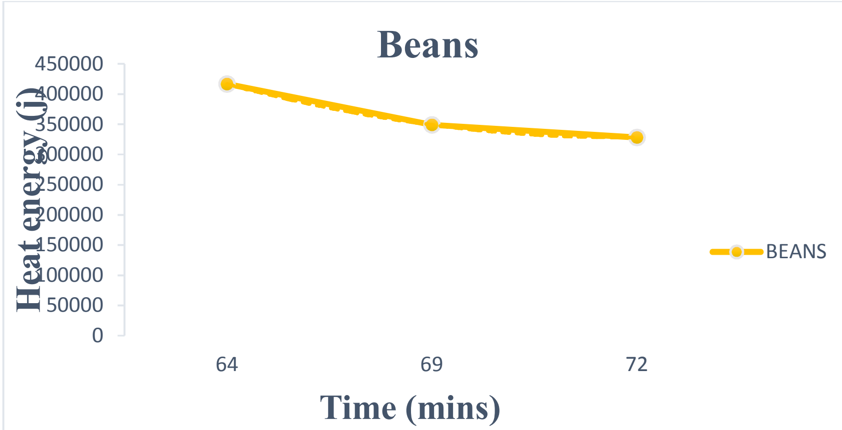

Fig. 8. Beans cooking energy versus time graph

3.5 Heat Energy Required for Okra Soup Moist-Heat Method

Table 4 shows that evaporation is prevalent in the preparation of okra soup. This explains why food gets drier when they are cooked [31]. The ingredients added into the soup at intervals during cooking, contribute to the quantity of water used up by the soup. Moist heat method ensures that the constant heat supplied to the food cooked in water based liquids (stocks and sauces) is used to avoid over-cooking [32]. The best heat energy for cooking okra soup with an automated cooking system is 199kJ in 14 minutes as shown Fig. 9. This shows that overcooking can be minimized given the ideal time listed for the cooking systems using Equation (7).

3.6 Heat Energy Required for Yam Caramerization

Caramization is responsible for the browning of food, especially when heat is applied to sugar [31]. This is possible because of the carbohydrate and starchy constituents of yam. While evaporation and gelatinization occurs within the cooking time of yam, Fig. 10 shows range of heat energy (182.2 kJ) that achieves different time for cooking yam with different systems which is similar to the 20 minutes time recommended by Anonymous [33] for making yam dough. The heating energy for cooking yam can be calculated with Equation (8).

3.7 Thermal Efficiency of the Auto-Cooker

Thermal efficiency is a dimensionless fraction of the energy added by heat that is converted to network output [34]. Inferring from the results captured in Table 5, the thermal efficiency of a food sample is a function of its corresponding heat energy. Given this thermal energy and efficiency relationship, we discovered that the thermal efficiency of the automated cooker is higher than the electric and gas cookers. Additionally, rice has the highest thermal efficiency of 91% due to its high heating energy followed by beans;73%, yam;34% and okra;32% in a descending order.

3.8 Evaluation and Comparison of the Foods Cooked Manually with Gas and Electric Cookers with the Automated Cooker

Since the average temperature of 80°C was measured during the cooking experiments of these food materials using a defined mass (200 g), it is therefore safe to deduce that the cooking time for any food is a function of the mass of food, volume of water and the heat energy with respect to the specific heat capacities of the foods. This clarifies the relationship between the selected food samples when cooked with the electric, gas or automated cooker as shown in Fig. 11.

By examining the relationship described in Fig. 11, the cooking time for each sample food would increase in proportion to the quantity of food (kg) and volume of water(L) used for cooking it. Furthermore, we noted that Okra soup has the shortest cooking time, while beans takes the longest cooking time when compared to the other food samples (yam and rice). This occurrence is due to the specific heat capacities and mass fraction of the food samples. From the cooking time information found in Fig. 11, it was observed that the automated cooker prepares food at a faster rate than the gas or electric cooker. The experimental models developed for each food sample show that polynomial expressions gave 100% accuracy in its time determining coefficient. And it could be used for estimating the heating energies for different cooking systems. By comparing the systems closely, it was found that the higher, the heating energy of the system, the lesser, the time it takes to cook the sample foods. The automated cooking system produced the highest heating energy and achieved the shortest time in cooking these foods illustrated in Fig. 11. The lagged internal parts of the automated cooker ensures that the heat generated by the system is properly used in cooking [24]. In an open environment (unconfined cooking systems), the ambient temperature influences the heat dissipated in the cooking system as well as the process. These uncontrolled factors (external temperature and pressures) affects the overall cooking time. Having compared all the cooking systems found within the scope of this study, the automated cooking is therefore ideal for achieving cooking in the shortest time. This phenomenon simplifies the precision adding of ingredients and water required for cooking with a digitally controlled framework.

3.9 Comparative Analysis of Automated Cooking System with Other Auto-Cookers

The automated cooking system provides a better advantage over the auto-cooker developed by Reema P et al. [35] with an unconfined cooking space. While both machines have the capacity for storing and dispensing several ingredients digitally, the motorized lid cover incorporated in the automated cooker makes it hygienic and suitable for cooking foods in an enclosed system. The automated cooking housing fastens the overall cooking time as well as reducing the thermal energy losses when compared with the Auto-cooker developed by Reema P et al. [35].

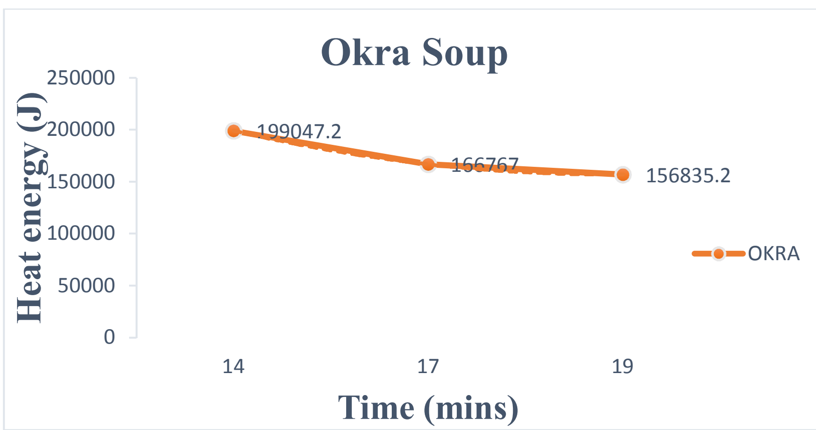

Fig. 9. Okra soup cooking energy versus time estimation

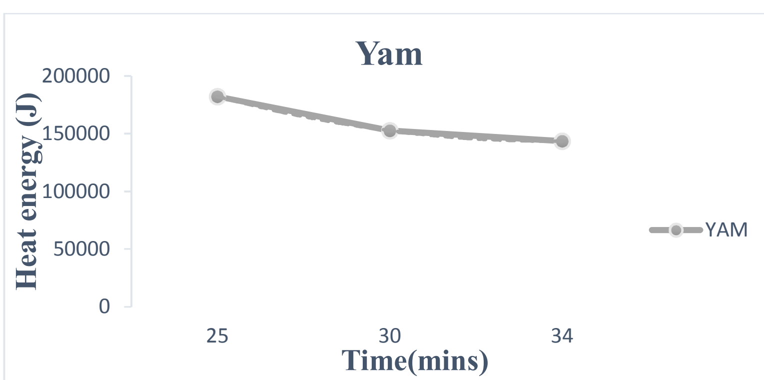

Fig 10. Yam cooking energy versus time relationship

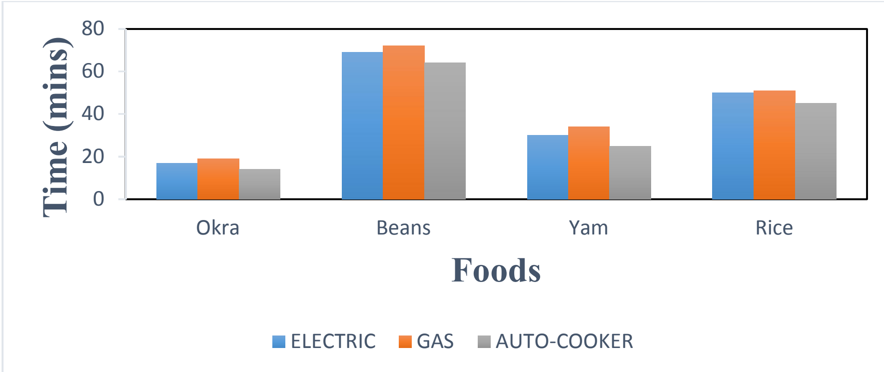

Fig. 11. Evaluation and comparison chart of food samples cooking time

Given that the electric rice cooker reduces the cooker's involvement in food preparation by simply measuring the rice, and preparing the rice manually using the correct amount of water [15]. The automated cooking system proves to be a versatile cooking machine. The incorporation of the automatic fluid and ingredient dispensers create an enjoyable and faster cooking experience.

The Programmable Logic Controlled based automatic cooking machine developed by Kumbhar VB et al. [17] is a novel invention. However, the absence of water or fluid dispensing unit and the non-renewable heating source makes the automated cooking system a better option for handling and cooking different foods with constant electricity supply.

The automated cooking machine developed by Kumar A et al. [19] has features similar to the studied automated cooker, but they didn't consider the cooking guideline for preparing Nigerian staple foods (Okra soup, beans and pottage yam) which can be done with the automated cooking system.

4. CONCLUSION

The study revealed that the automated cooking system achieved the shortest time in cooking the selected food samples (okra, beans, yam and rice), when compared to the electric and gas cookers due to the enclosed system of the automated cooker. The heating energy data (199 kJ, 416.72 kJ, 182.2 kJ and 516 kJ) calculated for the food samples using the automated system shows that the thermal efficiencies of the automated cooking system is higher than the thermal efficiencies of other cooking system (electric and gas cookers. This establishes the fact that cooking in an adiabatic and enclosed system such as automated cooker produces the highest heating energy because of minimal heat losses and it hastens the cooking process when compared with manual or automated cooking carried out in an unconfined environment. The lagged internal parts of the automated cooker ensures that the heat generated by the system is properly utilized in cooking [22]. The model equations derived in this research work can be used for predicting the heating energy and time required for cooking these food samples using gas cookers, electric cookers and in subsequent automated cookers. The automated cooker dispenses ingredients and water at a predetermined time according to the user's recipe and discretion. Having compared all the cooking systems found within the scope of this study, the automated cooking is therefore preferred for cooking in the shortest time. Hence, the auto-cooker is suitable for time efficient precision cooking.

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COMPETING INTERESTS

Authors have declared that no competing interests exist.

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APPENDIX

Table A1. Heat energy requirements for electric cooker

Food / C_p	Heat energy (kJ)	Cooking efficiency (E)
Okra (3.81 J/kg)	166.76	29
Beans (1.17 J/kg)	349.07	61
Yam (3.27 J/kg)	152.63	26
Rice (1.52 J/kg)	433.09	76

Note; C_p= specific heat capacity [19]

Table A2. Heat energy requirements for gas cooker

Food / C_p	Heat energy (kJ)	Cooking efficiency (E)
Okra (3.81 J/kg)	156.83	27
Beans (1.17 J/kg)	328.26	57
Yam (3.27 J/kg)	143.54	25
Rice (1.52 J/kg)	407.25	71

Note; C_p= specific heat capacity [19]

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