DEVELOPMENT OF EQUATIONS FOR ESTIMATING TIME, WATER AND ENERGY REQUIREMENTS IN DOMESTIC RICE COOKING

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ABSTRACT

A study was conducted to develop equations for estimating the time, water and energy requirements in domestic rice cooking using electric stove. A 3 x 2 x 2 factorial experimental design was employed. Rice variety (o*fada, bida* and royal stabilon), cooking method (open, closed) and quantity (173, 692 g) were the variables. The responses were time, water and energy requirements. Results obtained varied between 40 - 75 minutes for time requirement, 329.3 – 1933.4 g water and 2.4 – 4.3 MJ for energy requirement. Linear regression models were found to be the most suitable for estimating time, water and energy requirements with coefficients of determination R^2 of the equations ranging from 0.718 – 0.948. Analysis of variance of the data showed significant effects of treatment on the responses at 5% level of significance. Therefore, variety of rice, cooking method and quantity determine the time, energy and water requirements in rice cooking.

KEYWORDS: Rice cooking, time, water, energy, model.

1. INTRODUCTION

Rice is an important cereal for human consumption grown in all the ecological and dietary zones of Nigeria (Sanni et al., 2005)**.** The two commonly cultivated varieties of rice in Nigeria are *Oryza sativa and Oryza glabberima* (Abulude, 2004). Processing of rice involves the following unit operations, harvesting, threshing, cleaning, drying, parboiling, dehulling, de-braning, polishing, grading, packaging and cooking. Rice has potential in a wide range of food categories. Besides having nutritional and medicinal benefits, the by-products of rice are equally important and beneficial. By-products from growing rice create many valuable and worthwhile products. On the average, a sample of milled rice grown will contain about 80% starch, 8% protein, 0.5% ash and 11% water (Adekoyeni *et al.,* 2012).

Cooking requires the transformation of the potential energy in fuel into heat energy. There are many factors influencing the efficiency of cooking like the phenomenon of heat production, heat utilization, heat transmission and heat rejection during combustion. Rice is cooked by boiling or steaming. It can be cooked in just enough water (the absorption method), or it can be cooked in a large quantity of water which is drained before serving (the rapid-boil method). Rice may also be made into rice porridge by adding excess water so that the cooked rice is saturated with water to the point that it becomes very soft, expanded, and fluffy. Rice may be soaked prior to cooking using different cooking devices that depends on energy (Osaratin and Abosede, 2007).

Energy is an indispensable commodity for the economic growth and development of any nation. Energy is also an essential input to the growth and development of the various sectors of the economy. Energy is inevitable for poverty alleviation and provides services in the areas of health, communication and productivity. Knowledge of energy consumption in food processing is useful for several purposes such as budgeting, evaluation of energy consumption for a given product, forecasting energy requirement in a plant, and for planning plant expansion. Literature on estimation of energy input in food processing includes quantification of energy requirements for sugar-beet production in Morocco (Mrini *et al.,* 2002). Cashew nut processing operations (Jekayinfa and Bamgboye, 2006), palm-kernel oil processing operations (Jekayinfa and Bamgboye, 2007), energy utilization patterns in a sugar production factory in

Nigeria (Abubakar *et al.,* 2010) and bread baking (Akinoso and Ganiu, 2011) and *gari* processing (Akinoso and Kasali, 2012)

Nigeria is endowed with a wide range of renewable and non – renewable energy sources. The non – renewable resources include crude oil, natural gas, coal, lignite, tar and nuclear fuels (Wang 2009). The renewable ones include solar and wind energy. Nigeria operates a centralized energy system where communities and individuals are connected to a common energy source and because of the cost implication of connection to this source; many poor communities live without electricity. There is energy crisis in Nigeria; the cost of producing fossil fuels, which is predominantly the source of energy used in cooking, is expensive and electric power is unreliable.

Therefore, the objective of the study was to generate mathematical equations for estimating time, water and energy requirements for domestic cooking of rice, a widely consumed cereal in Nigeria. The models will aid energy conservation studies.

2. MATERIALS AND METHODS

2.1 Experimental Design

A 3 x 2 x 2 factorial experimental design was employed, that is three varieties of rice (*ofada, bida*, royal stabilion), two cooking methods (open, close) and two different quantities (173 g, 692 g). The variables were coded as variety, ofada (-1), bida (1), royal (0); methods open (-1), close (1) and quantity, 173 (-1), 692 (1). Responses were water consumption, time and energy requirement (Table 1). Data obtained were analyse using historical response surface (Design- expert version 6.0.6, Stat Ease Minneapolis, Minn).

2.2 Preparation of Materials

Bida (an indigenous Nigerian variety) and royal stabilion (Thailand) were procured from Bodija market, a local market in Ibadan, Oyo State Nigeria. While *ofada* (an indigenous Nigerian variety) was sourced from Abeokuta, Ogun state Nigeria. The extraneous matters such as stone and dirt inside *ofada* and *bida* rice were blown-off and removed by hand picking before the required quantities were weighed. The Digital weighing balance (model:Gx/GF-1 3003858,A&D company Limited) used was first set to zero before 173±3g (approximately 1tin cup) of o*fada* rice, *bida* rice, royal stabilion rice was weighed separately. This was also repeated for another quantity 692±5g (approximately 4 tin cups).

Table 1. Design matrix and responses

	Actual			Coded	
Variety	Method	Quantity	Variety	Method	Quantity
Ofada	Open	173	-1	-1	-1
Ofada	Open	692	-1	-1	1
Ofada	Close	173	-1	1	-1
Ofada	Close	692	-1	1	1
Bida	Open	173	1	-1	-1
Bida	Open	692	1	-1	1
Bida	Close	173	1	1	-1
Bida	Close	692	1	1	1
Royal	Open	173	0	-1	-1
Royal	Open	692	0	-1	1
Royal	Close	173	0	1	-1
Royal	Close	692	0	1	1

2.3 Cooking Methods

The three rice varieties of *ofada, bida* and royal stabilion rice were washed and cooked separately inside open and closed aluminum cooking pots (3mm thickness) using 1kW temperature regulated electric cooking plate (Crown star, Model MCHP-225, Rajko Traders Ltd, Hong Kong, China). The electric cooker was put on and left for 10 minutes to initialize before it was loaded.

2.4 Determination of Cooking Time

A trial experiment was first carried out to get approximate cooking time. After which, samples of the boiling rice were examined at 5 minutes interval by an experience analysis using sensory attributes. At close of cooking time assessment period was reduced to 3 minutes interval. This was continued until it was found satisfactory.

2.5 Determination of Water Requirement

The cooked rice was drained to remove excess water using sieve. This was left to stand for about 30 minute to equilibrate with ambient temperature 29±2. The difference between the weight of raw rice and cooked rice was recorded as quantity of water consumed (Osaratin and Abosede, 2007).

2.6 Determination of Energy Requirement

Energy utilization was quantified as a function of electrical power and time (Equation 1) (Akinoso and Kasali, 2012)

$$En = power\ x\ time \qquad 1$$

2.7 Statistical Analysis

All the experimental procedures were repeated three times. Mean values were recorded as obtained data. These were subjected to analysis of variance (ANOVA) at 5% level of significance. Regression equations were developed using propriety software package SPSS 14.0 for windows. The models were subjected to coefficient of determination and lack of fit test at 5% level of significance.

3. RESULTS AND DISCUSSION

3.1 Time Requirement

Recorded duration for cooking the variety and quantity of rice under consideration varied between 40 and 75 minutes. Effects of treatments were found to be significant on time requirement ($p< 0.05$). Cooking *bida* rice was fastest while royal stallion rice took longest duration. For all varieties of rice, close cooking took shorter duration. This is expected because closing the pot increases pressures thus the cooking rate. Using linear regression (Equation 2) to express the relationship gave high coefficient of determination (0.974), an indication of good fitness. Variety and quantity of rice were the significant model terms (Table 2). Khatoon (2006) reported similar observation. Graphical illustration of the relationship is presented as Fig. 1.

$$T = 57.42 - 3.25V - 2.08M + 11.75Q \qquad 2$$

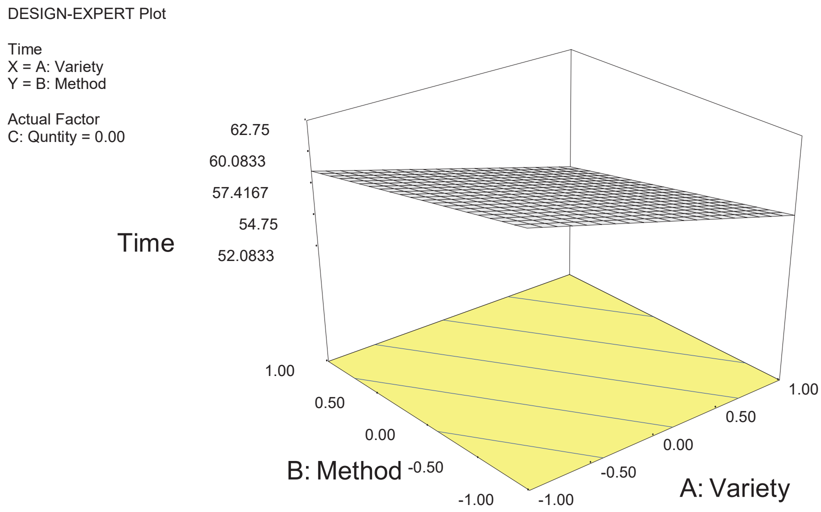

Figure 1. Response surface plot of time against cooking method and rice variety

Table 2. Analysis of variance of linear regression model for time requirement

	Un standardized coefficients		standardized coefficients		
Model	B	Std. Error	Beta	t	Sig.
Constant	57.417	1.008		56.948	0.000
Variety	-3.250	1.235	-0.211	-2.632	0.030
Method	-2.083	1.008	-0.166	-2.066	0.073
Quantity	11.750	1.008	0.936	11.654	0.000

3.2 Water Requirement

Highest quantity of water required to cook was 1933.4 g. This was recorded when 692 g of royal rice was cooked in a close pan. While the least water requirement of 329.2 g was obtained when 173 g of *ofada* rice was cooked in open pan. Level of water absorption is an indicative test for functional property. This result suggests that royal rice has highest water absorption and swelling capacities. This agreed with Osaretin and Abosede (2007) report on comparison of *ofada* and polished rice cooking rate. Analysis of variance of the data showed significant effect of treatments on water absorption capacity at 5 % level of significance. Mathematical expression of the relationship is presented as Equation 3. Coefficient of determinationR^2 of the model is 0.718. Test of significance of the model coefficients revealed quantity that quantity of cooked rice as the only independent significant model term (Table 3). This is suggesting that quantity as the major factor determining water requirement in rice cooking. Response surface plot of effects of the treatments on water requirement is shown in Figure 2.

$$W = 972.50 - 219.84V - 2.90M + 515.97Q \qquad 3$$

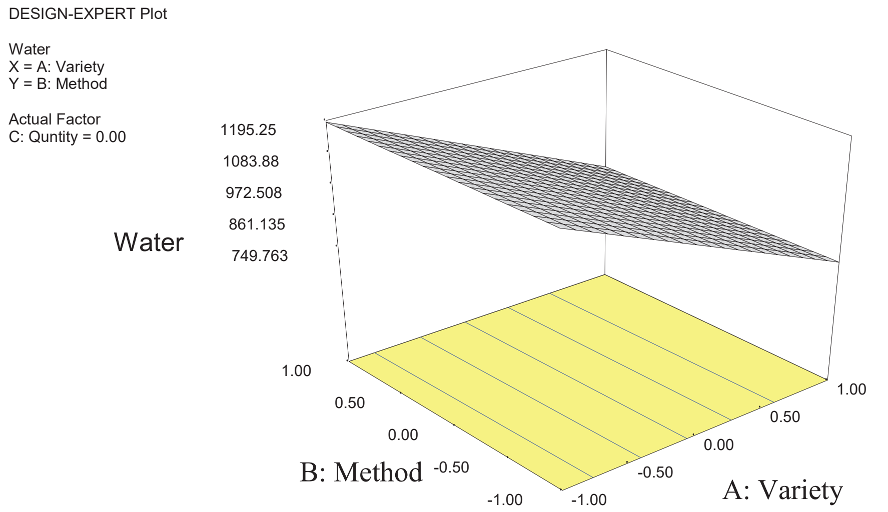

Figure 2. Response surface plot of water against cooking method and rice variety

Table 3. Analysis of variance of linear regression model for water requirement

	Un standardized coefficients		standardized coefficients		
Model	B	Std. Error	Beta	T	Sig.
Constant	972.503	121.107		8.030	0.000
Variety	-219.846	148.326	-0.278	-1.482	0.177
Method	-2.902	121.107	-0.005	-0.024	0.981
Quantity	515.978	121.107	0.800	4.260	0.003

3.3 Energy Requirements

Maximum and least energy expended were 4.3 and 2.4 MJ respectively, which is equivalent to energy intensity 6.21 MJ/kg and 13.87 MJ/kg. The energy expended was higher than 2.95 MJ/kg for bread making (Akinoso and Ganiyu, 2011). Higher energy intensity may be traced to quantity cooked, it is also an indication that electric stove consumes high energy. The treatments have significant effect on energy consumption at 5% level of significant. Linear model is fit to express the relationship (Equation 4). Coefficient of determination $R^2$of the model is high (0.948). Significant model terms of the equation were variety and quantity (Table 4). This is a revelation that variation in cooking method as no significant effect on energy demand. Figure 3 shows visual illustration of the relationship.

$$E = 3.445 - 0.195V - 0.125M + 0.705Q \qquad 4$$

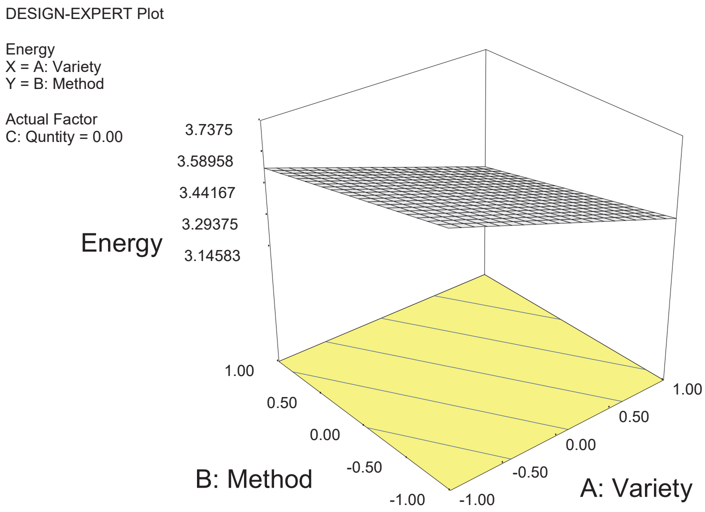

Figure 3. Response surface plot of energy against cooking method and rice variety

Table 4. Analysis of variance of linear regression model for energy requirement

	Un standardized coefficients		standardized coefficients		
Model	B	Std. Error	Beta	T	Sig.
Constant	3.445	0.060		56.949	0.000
Variety	-0.195	0.074	-0.211	-2.632	0.030
Method	-0.125	0.060	-0.166	-2.066	0.073
Quantity	0.705	0.060	0.936	11.654	0.000

4. CONCLUSION

This study has shown that variety of rice, cooking method and quantity determine the time, energy and water requirements in rice cooking. *Bida* rice cooking time was shortest while royal rice water requirement was the highest. Energy intensity of cooking the three varieties of rice using electric energy was low. Pot covering during rice cooking conserves time, water and energy. Co-efficient of determination of the regression equations (R^2) is high, indicating fitness of the model. Thus, the model is reliable and applicable.

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