Elucidations of energy, duration and cost of domestic cooking of African yam bean seed

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Abstract: Long duration of cooking limits domestic consumption of African Yam bean (AYB) seed, an edible legume. Reduction in energy demand during domestic cooking of AYB seed was the focus of the work. The seed was soaked in ambient temperature, and also cooked to determine hydration curve. AYB seeds (153 g) were cooked using kerosene, electric, Liquefied Petroleum Gas (LPG), and charcoal stoves. Normal, control, open and pressure cooking were done. Cooking duration, energy consumed, water evaporation and cost were determined using standard procedures. Moisture content of the seed increased with soaking time while rate of water absorption decreased. Temperature significantly (p<0.05) influenced both moisture content and water absorption rate. Energy consumption varied with methods of cooking regardless of energy source. Pre-soaked control pressure cooked method consumed least energy using kerosene (4,849.7 kJ), electric (3,085 kJ), and LPG (2,673 kJ) stoves. Pre-soaked pressure control electric cooking method was the cheapest energy source (US $0.071), although not significantly different from pre-soaked pressure control LPG (US $0.075). While un-soaked open normal kerosene method was most expensive (US $0.342). Shortest cooking time of 55 minutes was recorded in pre-soaked pressure normal electric stove while un-soaked open control LPG method duration of 170 minutes was the longest. Opening and closing of pot majorly determined the energy loss due to evaporation. Generally, controlled energy input, cooking at high pressure, and soaking of AYB seeds before cooking independently reduced the energy required for cooking.

Keywords: African yam bean, seed, hydration behaviour, cooking method, energy source

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1 Introduction

Energy is the prime mover of any economy and engine of growth around which all sectors of economy revolve. Therefore, improvement on energy generation, estimation and conservation is important for the development of industries and nation at large (Wang, 2009). Effective energy utilization and energy source management in food processing facilities are desirable for reducing processing costs, conserving non-renewable energy resources, and reducing environmental impact (Akinoso and Omolola, 2011). In recent time, there has been a greater awareness of the energy problems facing the world than at any other period in history (Wang, 2009). It is now widely accepted that the current rate of energy generation and supply cannot match the rapid growth in energy consumption rate (Akinoso, et al., 2013). In order to reduce the operating and maintenance costs to a minimum, the cost of energy consumption, which is the prime factor under operating cost in industries must be monitored (Wang, 2009). Roy et al., (2004) reported that the household sectors utilize a large portion of energy in developing countries and more than half of that amount is being used in domestic cooking.

Cooking is the process of preparing food with the use of heat that alters the structure of food components such as starch, protein, fat, fiber and vitamins. The process increases palatability, destroys pathogenic organisms and

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anti-nutritional factors. Cooking techniques and ingredients vary widely across the world, reflecting unique environmental, economic, and cultural traditions. African Yam Bean (AYB) seed (*Sphenostylis stenocarpa*) is an edible legume widely cultivated in many African countries (Adewale et al., 2013). Long duration of cooking limits its domestic consumption. Considering the huge energy consumed daily as a result of cooking, there is an urgent need for conservation of energy and efficient utilization of energy. Amarasekara (1994) reported the possibilities of energy conservation during cooking. Reduction in energy demand during domestic cooking of AYB seed was the focus of the work.

2 Materials and methods

2.1 Hydration at ambient temperature

African Yam Bean (AYB) seed was soaked in excess water at room temperature (29±2^{o}C). Soaked samples were drawn at different time interval of 20 minutes up to two hours and 30 minutes from two hours to five hours. Moisture content of each sample drawn at those intervals were determined using oven drying method. Hydration curve was obtained by plotting the moisture content (% w.b.) of AYB seed against soaking time.

2.2 Hydration at cooking temperature

A known quantity of 2 kg water was boiled over an electric coil stove after which a measured quantity of African yam beans (153 g) was added. The content was heated continuously at the same constant temperature of 105^{o}C for a period of about two hours which was recorded. Periodically, cooking stage was assessed and the moisture content was determined by oven dry method. This was done by taking out samples of 5 g at time intervals during cooking (five minutes). The temperature of the AYB seed was recorded at that time interval using a thermocouple that was fixed at an appropriate position. This cooking in excess water was done for both pre-soaked and un-soaked African yam bean. The moisture content of completely cooked AYB seed was measured and recorded. The moisture content that was obtained at various intervals was plotted against time.

2.3 Rate of water absorption

Rate of absorption was determined by calculating the water uptake (Equation (1)) and divided by time required for that water to be taken up (Equation (2)). The rate of absorption of water was plotted against time.

$$\text{Water uptake} = \text{intial weight of sample after soaking} - \text{weight after drying} \quad (1)$$

$$\text{Rate of water absorption} = \frac{\text{Water uptake}}{\text{time}} \quad (2)$$

2.4 Moisture distribution in cooked African yam bean seed

After cooking, samples were taken at different location of different layer to determine the moisture content using oven dry method (ASABE, 2008). The location where sample were taken are shown in Figure 1. Location A and B were considered peripheral 1 and 2 while location C was considered as centre. The moisture content at the locations A, B, and C were plotted against the layers 1, 2, 3, 4 and 5. The moisture content of AYB seed was determined by weighing constant weight as soaking and cooking continued precisely 5 g of each sample into a pre-weighed crucibles. The samples were dried at 105ºC for 24 hrs (in duplicate) to a constant weight. The loss in weight was recorded as water absorbed and moisture content was calculated using ASABE 2008 method (Equation (3))

$$\text{Moisture cont} = \frac{\text{Weight of sample before drying-weight of sample after drying}}{\text{Weight of sample (5 g)}} \times 100\% \quad (3)$$

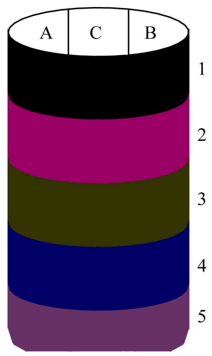

Figure 1 Moisture distribution in cooked AYB seed

2.5 Cooking

Experiments were conducted for both pre-soaked (soaked in water before cooking) and un-soaked (cooked without soaking) AYB seeds. This was done by boiling the 153 g of AYB seed in 0.5 kg. Boiling water of known quantity (0.5kg) was added when necessary until satisfactorily cooked seed was achieved. The cooking was done using a 3 mm thick aluminium pot and pressure pot to determine ON time, total cooking period, mass of fuel used, energy consumed, water evaporation loss and energy loss from evaporation. The evaluation was done using four different heat sources namely electrical, kerosene, Liquefied Petroleum Gas (LPG) and charcoal stoves. The cooking was done in two modes for both open cooking (without pressure) and pressure cooking (with pressure pin) and this include normal and control cooking. The flow pattern of the procedure of the experiment is shown in Figure 2.

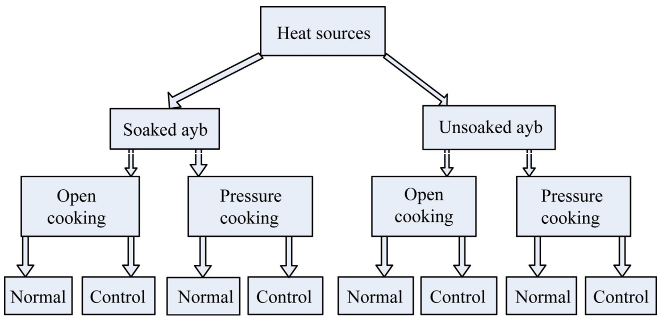

Figure 2 Flow chart of experimental procedures

2.6 Normal and controlled cooking

In normal cooking, the cooking was done by continuous heating from beginning to the end of cooking while the control cooking was conducted to save energy by controlling energy input to closely match the actual energy required for cooking (Amarasekara, 1994). Temperature was monitored and the heat input was cut off whenever the temperature of the content (AYB seed and water) reaches boiling point (100^{o}C) and was resumed whenever the temperature fell just below 90^{0}C. This strategy of controlled heat input was continued till the AYB seed cooked. This was adapted to control or prevent excessive evaporation of water resulting in energy saving. Cumulative ON time was computed. On the other hand, normal cooking involves direct cooking without any control of energy input.

2.7 Pressure and open cooking

The sample was cooked in pressure pot of 15 psi. During pressure cooking, the burner was switched OFF soon after the required number of whistles (4 whistles) occurred and the pressure pot was removed from the stove and left undisturbed for 10 minutes. Open cooking involves cooking of sample in 3 mm thick aluminium pot.

2.8 Identification of cooking end point

Cooked AYB seed was identified by using Das et al., 2006 method. The test was done by sticking the beans to the pint of the sharp knife edge. Hardness test was also conducted by using the thumb and index finger to apply slight pressure on the cooked bean. The cooked beans usually pressed when the pressure was applied.

2.9 Period of cooking

This was determined by using stop watch. In controlled cooking, the stop watch was started when the power was on and stop when the power was put out. The ON time was summed together to calculate the cooking period using Equation (4). For normal cooking, the stop watch was read directly as it did not require on and off of the energy sources.

$$T = t_1 + t_2 + t_3 + t_4 + t_5 \tag{4}$$

where, T = total cooking time, $t_1 + t_2 + t_3 + t_4 + t_5$ = ON-time.

2.10 Fuel quantity and energy

The fuel quantity was calculated by measuring the initial weight of the stove or cylinder before cooking. Also the weight was measured after cooking. Cooking energy was calculated by multiplying the quantity of fuel used with the caloric value of the specific fuel. Equations (5), (6), and (7) were used for kerosene, charcoal and LPG stoves respectively. In the case of electric stove that did not require burning of any quantity of fuel, the basic formula of electrical energy was used by multiplying the power rating of the stove by time taken (Equation (8))

$$E_k = (M_{k1} - M_{k2})C_k \tag{5}$$

$$E_c = (M_{c1} - M_{c2})C_c \tag{6}$$

$$E_g = (M_{g1} - M_{g2})C_g \tag{7}$$

$$E_e = p \times t \tag{8}$$

where, M_k, M_c and M_g are masses (kg) of kerosene, charcoal and gas used respectively; E_k, E_c and E_g are energy (kJ) utilised during cooking with kerosene, charcoal and LPG respectively; Subscript 1 and 2 indicate initial mass before cooking and final mass after cooking; C_k - caloric value of kerosene = 43110 kJ/kg (GREET, 2010); C_c - caloric value of charcoal = 31930 kJ/kg; C_c -

caloric value of LPG = 47700 kJ/kg; E_e - energy consumed during cooking with electric stove; p - power rating (W); t - Cooking duration (min).

2.11 Water evaporation loss

The quantity of water and beans was measured before and after cooking. Increase in weight of cooked beans indicated water absorbed while the rest of the water loss was water evaporation loss. The water evaporation loss was calculated using Equation (9). Energy embedded in vapour was calculated using Equation (10).

$$M_w = (am_1 + M_{w1}) - (bm_2 + M_{w2}) \quad (9)$$

$$E_w = M_w(C\Phi+L) \quad (10)$$

where, M_w (kg) - mass water evaporation loss after cooking; m_1(kg) - mass of uncooked AYB seeds; M_{w1} - mass of water added before cooking; m_2 - mass of uncooked AYB seeds; M_{w2} - mass of drained water after cooking; a - water component of uncooked AYB seed = 6% for un-soaked and 20.6% for soaked AYB seeds; b - water component of cooked AYB seed =75% for un-soaked and 78% for soaked AYB seeds; E_w - energy loss from water evaporated; M_w - mass of water vapourised; C = specific heat capacity of water; L = latent heat of vaporization; Φ = temperature differential.

2.12 Cost analysis

Cost of cooking, a major factor considered when cooking methods and energy sources are selected in domestic cooking was examined in different methods of cooking and across different sources of energy. The cost of cooking AYB seed was calculated by multiply the quantity of fuel used by the corresponding prices obtainable in the market (Equations (11) to (13)). In the case of electric cooker as a source of energy, the unit of power consumed was multiplied by power rating of the area (Equation (14)).

$$C_k = (p_k \times M_k)/0.8171 \quad (11)$$

$$C_c = (M_c \times p_c)/1 \quad (12)$$

$$C_g = (M_g \times p_g)/1 \quad (13)$$

$$C_e = E_e \times p_e \quad (14)$$

where, C_k, C_c, C_g and C_e are cost of cooking using kerosene, charcoal, LPG and electricity.

2.13 Statistical analysis

All the procedures were replicated and mean data recorded. Data were subjected to ANOVA at p<0.05.

3 Results and discussion

3.1 Hydration behaviour

The initial moisture content of AYB seed was 6%. Moisture content of the seed increased with soaking time while rate of water absorption of the samples showed reverse trend for all conditions of soaking (Figures 3 and 4). Temperature significantly (p<0.05) influenced both moisture content and water absorption rate. Water uptake by AYB seeds resulted in loss of apparent homogeneity of the microscopic particles of the seeds. In addition, penetration of water into the particles might have initiated dilution of compact arrangement of the particles which eventually led to free flow of water into and out of the seeds thereby allowing faster collision of water molecules with particles as a result of wider space of movement of water. Swelling of the seed was noticed, this is likely to reduce mechanical properties of the seed. Compressive strength and deformation of pigeon were functions of the cooking duration (Akinoso and Lasisi, 2013). Therefore, possibility in reduction of duration and energy requirements for cooking AYB seed by soaking is high. Moisture content of the samples varied with layers in polynomial curve (Figure 5). Highest moisture content (78%) was recorded at centre point of the third (middle) layer, while least moisture content (51%) was also obtained at first (surface) layer of centre point of the pot. Moisture content did not vary significantly with location but with layers. This was as a result of uneven distribution of heat as well as higher rate of evaporation at the surface layer. Das et al. (2006) and Lakshmi et al. (2007) reported similar observations for rice cooking. This may be due to the uniformity of heat and mass transfer during cooking of pre-soaked grains as reported by Chakkaravarthi et al. (2008).

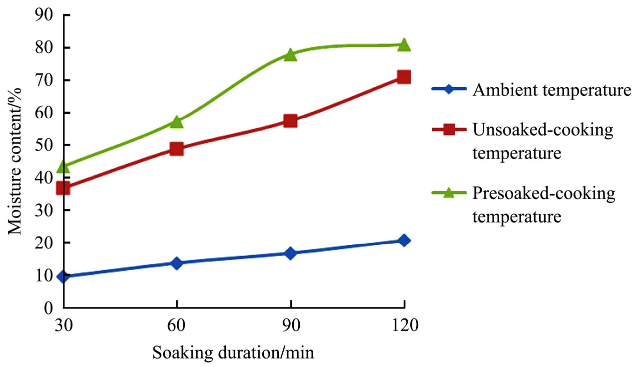

Figure 3 Effect of temperature on moisture content of AYB seed

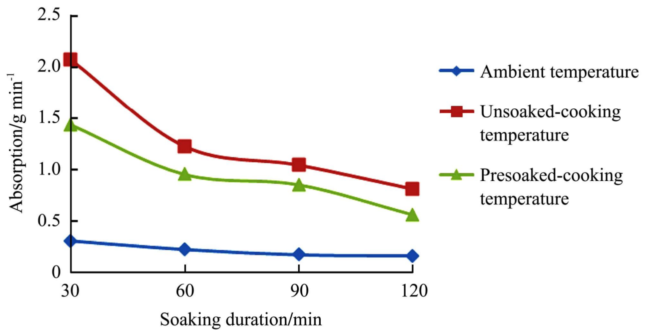

Figure 4 Effect of temperature on rate of moisture absorption of AYB seed

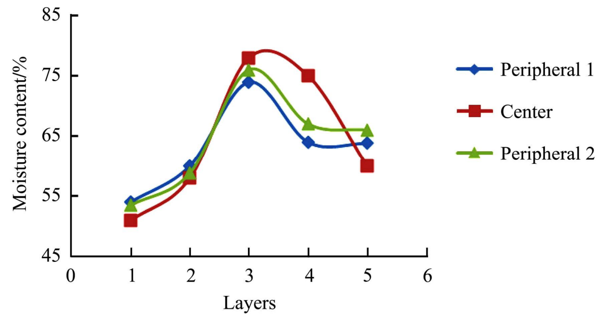

Figure 5 Sample moisture content at different locations in the pot

3.2 Cooking energy

Energy consumption varied with methods of cooking regardless of energy source. Pre-soaked control pressure cooked method consumed least energy for cooking 153 g of AYB seed using kerosene (4,849.7 kJ), electric (3,085 kJ), and LPG (2,673 kJ) stoves (Table 1). However, for charcoal stove where control cooking is not possible, pre-soaked pressure demanded least energy (58,044 kJ). Cooking under pressure reduces energy and cooking time because elevated cooking temperature (Akinoso, et al., 2012). Highest energy consumption for kerosene, electric, LPG and charcoal stoves were 12,933, 6,900, 5,150 and 83,044 kJ respectively. For all the sources of energy, un-soaked normal cooking of AYB seed demanded highest energy (Table 1). By soaking, water replaces air within particles of the food and this conduct heat better and makes its cooking faster and also conserves energy (Amarasekara, 1994). Energy sources and cooking methods significantly (p<0.05) affect energy demand. The effects of pressure cooking, control cooking and soaking before cooking were more pronounced. There was no significant difference between energy consumption of pre-soaked open control and pre-soaked pressure normal cooking methods using LPG. Generally, LPG energy demand was low while charcoal stove demand was the highest. Amarasekara (1994) reported 75 and 20% as energy efficiency of LPG and charcoal stove respectively. This may be due to complete combustion of LPG while larger percentage of energy generated by charcoal was lost to the surrounding. In addition, LPG has the highest heating value (47,700 kJ/kg), kerosene (43,110 kJ/kg) and charcoal (31,930 kJ/kg) (GREET, 2010).

3.3 Cooking cost

The prices of energy vary from one energy source to another. It also varies periodically as it fluctuation depend on both local and international regulations. Geographical location is also factor that determines the energy cost. The cost of energy within the frame of this research was based on what was obtainable as at the time that this research was done in June 2013 in Ogbomoso, Oyo state Nigeria. Pre-soaked pressure control electric cooking method was the cheapest energy source (US $0.071), although not significantly different from pre-soaked pressure control LPG (US $0.074) (Table 1). While un-soaked open normal kerosene method was most expensive (US $0.342). It is worth to note that pre-soaked pressure normal charcoal method cost was relatively low (US $0.087).

3.4 Cooking duration

Shortest cooking time of 55 minutes was recorded in pre-soaked pressure normal electric stove while un-soaked open control LPG method duration of 170 minutes was the longest (Table 1). Cooking methods significantly influence duration. Duration is a major factor in selection of cooking methods, sources of energy and preference for food. Although control cooking conserves energy and reduces cost, it is not desirable for time conservation. Among the control methods, electric stove duration was the shortest; this may be attributed to the ability of heating element to store heat energy. This is because material (ceramic) that houses the heating element possesses low thermal conductivity (0.25-2.0 W/mK), a potential for retaining heat and high temperature during control cooking. Energy conservation of ceramic insulated oven was high (Akinoso and Ganiu, 2011). Forno (2012) reported thermal mass and insulation to be the two primary characteristics that describe an oven's ability to absorb and hold heat, and make it useful for cooking.

3.5 Energy loss as vapour

Estimated energy loss due to vapour loss is presented in Table 1. As expected, opening and closing of pot determined the energy loss. This is associated to the fact that cooking in closed container (pressure cooking) utilised energy more efficiently as the latent heat that charged the vapour was recycled. Energy sources with high heating value lose more energy. Energy loss due to vapour was the highest in LPG stove while electric stove was the least (Table 1). It is known that temperature is one of the major factors determining the rate of water evaporation. High flame amounts to high energy loss, thus operating the stove at moderate burning flame promotes energy conservation.

Table 1 Effect of cooking methods on energy, time and cost of cooking

Cooking Methods	Energy loos/kJ	Cooking duration/min	Energy/kJ	Cost/US $
Un-soaked open normal kerosene	4343	$130±1.00^{r}$	$12933±1.00^{v}$	$0.34±0.10^{p}$
Un-soaked open control kerosene	1047	$140±1.00^{u}$	$6466.5±1.10^{r}$	$0.17±0.20^{l}$
Un-soaked pressure normal kerosene	3184	$106±1.00^{jk}$	$9053.1±0.68^{t}$	$0.24±0.50^{n}$
Un-soaked pressure control kerosene	397	$118±0.53^{o}$	$5658±0.95^{o}$	$0.15±1.00^{j}$
Pre-soaked open normal kerosene	3514	$112±0.95^{m}$	$10508±1.00^{u}$	$0.28.8±0.20^{o}$
Pre-soaked open control kerosene	947	$135±1.00^{t}$	$5658±0.50^{o}$	$0.15±0.30^{j}$
Pre-soaked pressure normal kerosene	2394	$92±1.00^{e}$	$5518±0.91^{n}$	$0.23±0.04^{m}$
Pre-soaked pressure control kerosene	397	$134±1.09^{t}$	$4849.7±1.00^{l}$	$0.13±0.25^{g}$
Un-soaked open normal electric	4087	$115±1.00^{n}$	$6900±1.00^{s}$	$0.12±0.20^{k}$
Un-soaked open control electric	664	$125±0.50^{q}$	$4140±0.72^{j}$	$0.09±0.20^{d}$
Un-soaked pressure normal electric	2964	$105±0.76^{ij}$	$6300±0.76^{q}$	$1.45±0.31^{j}$
Un-soaked pressure control electric	264	$107±0.55^{k}$	$3622.5±1.00^{g}$	$0.08±0.14^{b}$
Pre-soaked open normal electric	2810	$95±0.45^{f}$	$5700±1.00^{q}$	$1.31±0.10^{h}$
Pre-soaked open control electric	1354	$114±1.00^{n}$	$3600±1.20^{f}$	$0.08±0.40^{b}$
Pre-soaked pressure normal electric	317	$55±0.00^{a}$	$3507.6±1.05^{e}$	$0.08±0.20^{b}$
Pre-soaked pressure control electric	635	$85±0.42^{d}$	$3085.7±1.00^{c}$	$0.07±0.10^{a}$
Un-soaked open normal LPG	4474	$134±1.00^{t}$	$5150±0.95^{m}$	$0.15±0.50^{j}$
Un-soaked open control LPG	1767	$170±0.50^{v}$	$4293±0.95^{k}$	$0.12±0.20^{f}$
Un-soaked pressure normal LPG	2594	$102±0.10^{h}$	$3818.8±1.00^{h}$	$0.12±0.20^{f}$
Un-soaked pressure control LPG	839	$120±1.00^{p}$	$3876.6±1.00^{i}$	$0.10±0.50^{e}$
Pre-soaked open normal LPG	1921	$110±1.00^{l}$	$3339±1.00^{d}$	$0.09±0.50^{d}$
Pre-soaked open control LPG	1098	$104±0.66^{i}$	$2862±1.16^{b}$	$0.08±0.55^{b}$
Pre-soaked pressure normal LPG	1561	$80±0.75^{b}$	$2862±1.00^{b}$	$0.08±0.35^{b}$
Pre-soaked pressure control LPG	555	$92±0.36^{e}$	$2673±1.00^{a}$	$0.07±0.40^{a}$
Un-soaked open normal charcoal	4087	$112±0.61^{m}$	$83044±1.00^{z}$	$0.27±0.46^{o}$
Un-soaked pressure normal charcoal	3705	$102±0.08^{h}$	$71865±1.00^{y}$	$0.24±0.55^{n}$
Pre-soaked open normal charcoal	3123	$97±1.00^{g}$	$67070±1.00^{x}$	$0.22±0.22^{m}$
Pre-soaked pressure normal charcoal	2699	$82±0.90^{c}$	$58044±1.01^{w}$	$0.08±0.20^{c}$

4 Conclusions

Soaking at ambient temperature can increase AYB seeds moisture content by 20%. Temperature and pre-soaking accelerate the rate of water uptake of the seed. Controlled energy input, cooking at high pressure, and soaking of AYB seeds before cooking independently reduced the energy requirement for cooking. In addition, combined effects of these parameters save energy and cost. Considerable energy is lost to vapour. Control cooking is not desirable using charcoal as heat source. Preferred energy source for cooking AYB seed in terms of energy and duration are LPG and electric respectively. Both electric and LPG are equally rated on cost. Use of kerosene stove for cooking AYB seed is relatively expensive, time and energy consuming.

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