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Energy utilization and conservation in instant- pounded yam flour production

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Abstract

Pounded yam is a highly valued staple food in many African countries. However, the traditional method of processing the food using pestle and mortar is discouraging consumption among elite. Instant-pounded yam flour is a developed product to solve the problem. Therefore, this study quantified energy utilization in the preparation of yam flour for the production of instant-pounded yam and developed energy conservation processing method.. Data were collected from six instant-pounded yam producing factory using structured questionnaires, oral interview, and direct data recording of processing parameters. Data obtained were used to energy requirements and distribution pattern. Energy input for peeling, washing, slicing, cooking, drying, milling and packaging were quantified using standard equations. In attempt to conserve energy, thickness and shape of the yam to be dried were varied, and energy input estimated. Estimated energy inputs for processing 1000 kg of yam into instant-yam flour were 55.36MJ, 3.06MJ, 6.89MJ, 1490.13MJ, 4313.50MJ, 406.02MJ and 200.11MJ for peeling, washing, slicing, cooking, drying, milling, and packaging operations, respectively. Total energy expended in converting raw yam into instant-pounded yam flour was 6.4MJ/kg. Variation in thickness and shape of sliced yam did not affect magnitude of energy required for peeling, washing, and packaging. However, reducing yam thickness by 5 mm and changing shape from cylindrical to diagonal, reduced energy requirements for cooking, drying, and milling by 4.59%, 18.42%, and 2.60% respectively. The conservation approach reduced total energy utilization from 6425.07 to 4779.42 MJ. Finding of the work revealed that it is possible to conserve energy during production of instant-pounded yam using procedural and behaviour approach.

Introduction

Yam (*Dioscorea* specie) is an important tropical root crop. It constitutes a nutritious, high carbohydrate and fibre food source. Other nutrients present in yam are caloric proteins, minerals and vitamins (Onwueme and Charles, 1994). The crop is important in household food security, diet diversification, employment and income generation as well as alleviation of poverty. Yams are ranked as the fourth major root crop in the world after cassava, potatoes and sweet potatoes (Adeleke, 2010). Yams are characterized by high moisture content, which renders the tubers more susceptible to microbial attacks and brings about high perish ability of the tubers. With annual production of above 28 million metric tonnes (FOS, 2011), Nigeria is the world's largest producer of edible yams, with *D. rotundata* and *D. alata* as the two most cultivated yam species in the country.

Industrial processing and utilization of yam includes starch, poultry and livestock feed, production of yam flour and instant-pounded yam flour production. Traditionally, the processing of pounded yam using pestle and mortar is highly valued but is gradually being replaced in the market with instant-pounded yam flour. Instant pounded yam flour requires short processing time and less energy. The aim of the practice was to preserve yam and reduce human drudgery associated with pounded yam production (Komolafe and Akinoso, 2005). The technology includes peeling, washing, slicing/dicing, cooking, drying, milling and packaging.

The food industry is one of the energy-intensive industries (Singh, 1986). Energy efficiency, environmental protection and food processing waste management have attracted increasing attention in the food industry. Effective energy utilization and energy source management in food processing facilities are desirable for reducing processing costs, conserving non-renewable energy resources, and reducing

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environmental impact. 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 (Aiyedun *et al*., 2008). The importance of energy in sustained economic development is a well accepted fact.

The efficiency of energy utilization in a manufacturing industry requires the knowledge of energy performance of machines, plants and all the parameters directly associated with the production process. The need to conserve energy in manufacturing industry is of paramount importance. 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 must be monitored (Wang, 2009). Energy and exergy efficiencies in food processing facilities vary with end users and production lines. Procedural and behavioural changes, which include avoiding wastages, can save about 30% energy without capital investment (Fischer *et al*., 2007). Available literature on estimation of energy input in food processing include sugar-beet production (Mrini *et al*., 2002), bread baking (Jekayinfa, 2007), cassava products processing operations (Jekayinfa and Olajide, 2007), palm-kernel oil processing operations (Jekayinfa and Bamgboye, 2007), bread making processes (Le-bail *et al*., 2010), sugar production factory (Abubakar *et al*., 2010) and cashew nut processing mills (Atul *et al*., 2010).

Energy of different forms and quantity are required to carry out each unit operation involved in instant-pounded yam flour production. These include heat or thermal, mechanical, electrical and human energies. Profiling energy utilization data and developing energy conservation processing methods will improve sustainability in the food processing industry (Mohammed, 2009). In Nigeria today, a lot of energy is wasted because industries, power companies, offices and households use more energy than is actually necessary to fulfill their needs. With energy efficiency practices and products, the nation can save large proportion of present energy consumption (Aiyedun *et al*., 2008). Therefore, the objectives of this study are to quantify energy utilization in the industrial preparation of yam flour for the production of instant-pounded yam and developed energy conservation processing method.

Materials and Methods

Research instruments

Data were collected from six instant-pounded yam flour producing factory using structured questionnaires, oral interview, and direct data recording of processing parameters. Information gathered included production unit operations involved, production capacity, equipment used, sources of energy, time taken, gender and number of labour requirements for processing 1000 kg of yam into instant-pounded flour yam. Data obtained were subjected to descriptive statistical analysis. Mean values were recorded as obtained data.

Energy analysis

During the production of instant-pounded yam flours, some levels of energy input is required at each stage of the unit operations, in forms of electrical energy, thermal energy and human energy. The type and magnitude of the energy input is a function of the technology employed. Equations 1 - 7 were employed as applicable (Wang, 2009). Unit operations considered were peeling, washing, slicing, cooking, drying, milling and packaging. Data collected from factories were used for the calculation (Table 1).

$E = MNt$ (1), for operations using male labour only

$E = FNt$ (2), for operations using female labour only

$E = MNt + FNt$ (3), for operations using both male and female labour only

$E = KX_1$ (4), for operations using kerosene as source of energy only

$E = KX_1 + FNt$ (5), for operations involving use of kerosene and female labour

$E = ZPt$ (6), for operations involving use of electrical energy

$E = DX_2 + (ZPt + MNt)$ (7), for operations involving use of diesel, electrical energy and male labour

where

E is quantity of energy (MJ)

M is the average power input by a male labour (0.75 MJ/h) (Abubakar *et al*., 2010)

F is the average power input by a female labour (0.68 MJ/h) (Abubakar *et al*., 2010)

N is the number of persons involve in an operation

t is the time to complete the operation (h)

K is the caloric value of kerosene

X1 is the quantity of kerosene used (L)

D is the caloric value of diesel

X2 is the quantity of diesel used (L)

Z is the power factor of the machine

P is quantity of electrical energy used (KWh)

Energy conservation approaches

Experiment was conducted to determine the effect of yam thickness, shape and electric motor output efficiency on energy requirements for instant-pounded yam flour production. Instant pounded yam

Table 1. Data used in energy requirements estimation ‡

Unit operation	Fuel (L)	Cal. value (MJ/L)	Electricity (kW)	Time (h)	Number labour^Ғ	Labour gender
Peeling	-	-	-	0.9±0.1	9.0±1.4	Female
Washing	-	-	-	0.5±0.0	9.0±1.4	Female
Slicing	-	-	-	1.1±0.5	9.0±1.4	Female
Cooking	48.0±2.8	31.0±0.0	-	0.6±0.1	5.0±1.4	Female
Drying	137.5±17.7	31.0±0.0	-	17.0±1.4	4.0±0.0	Male
Milling	11.0±1.4	36.0±0.0	0.3±0.0	1.0±0.0	4.0±0.0	Male
Packaging	5.5±0.7	36.0±0.0	0.3±0.0	1.0±0.0	2.0±0.0	Male

‡ Mean of six replicates
Ғ Approximate to nearest whole number

Table 2. Data input after conservation approach ‡

Unit operation	Fuel (L)	Cal. value (MJ/L)	Electricity (kW)	Time (h)	Number labour Ғ	Labour gender
Peeling	-	-	-	0.9±0.1	9.0±0.0	Female
Washing	-	-	-	0.5±0.0	9.0±0.0	Female
(Slicing)	-	-	-	1.3±0.0	9.0±0.0	Female
Cooking	38.5±3.7	31.0±0.0	-	0.4±0.1	5.0±0.0	Female
Drying	100.0±9.0	31.0±0.0	-	10.0±0.8	4.0±0.0	Male
Milling	6.5±1.3	36.0±0.0	0.3±0.0	0.4±0.0	4.0±0.0	Male
Packaging	5.5±0.9	36.0±0.0	0.3±0.0	1.0±0.2	2.0±0.0	Male

‡ Mean of three replicates
Ғ Approximate to nearest whole number

flour was produced by method described by Komolafe and Akinoso (2005). The process were peeling, washing, slicing, cooking for 15 min, drying at 60^{o}C, milling using hammer mill and packaging. Based on the theory that thickness of materials is among the factors controlling drying rate (Mohammed, 2009), thickness of the yam was reduced by 5 mm. In practice 20 mm thickness yam is used. This was reduced to 15 mm. In addition, the shape of the yam was changed from conventional cylinder to diagonal. Electric motor with higher efficiency power output was used to power the milling and sealing machines. Instead of 0.65 power factor (output efficiency) of the electric motor in use, power output efficiency of 0.85 was used in calculating electrical energy. Data obtained were substituted to Equations 1 to 7 to estimate energy expended. Data obtained from the experiment were used in calculation (Table 2).

Results and Discussion

Energy utilization pattern

The energy requirements for peeling, washing, slicing, cooking, drying, milling and packaging were 5.36MJ, 3.06MJ, 6.89MJ, 1490.13MJ, 4313.50MJ, 406.02MJ and 200.11MJ respectively (Figure 1). Thus, the total energy expended in converting 1000kg of raw yam into instant-pounded yam flour was 6425.07 MJ. This is equivalent to 6.4 MJ/kg. The energy expended was higher than 0.316 MJ/kg reported for production of cassava flour (Jekayinfa and Olajide, 2007). The differences may be traced to the crops physiology and technology involved. Percentage proportion of energy used showed that

Table 3. Energy requirements using traditional and improved methods

Unit operations	Traditional method (MJ)	Improved method (MJ)	Difference	Percentage difference
Peeling	5.36	5.36	0.00	0.00
Washing	3.06	3.06	0.00	0.00
Slicing	6.89	7.65	-0.76	-0.01
Cooking	1490.13	1195.06	295.07	4.59
Drying	4313.50	3130.00	1183.50	18.42
Milling	406.02	238.18	167.84	2.61
Packaging	200.12	200.12	0.00	0.00
Total	6425.07	4779.42	1645.65	25.62

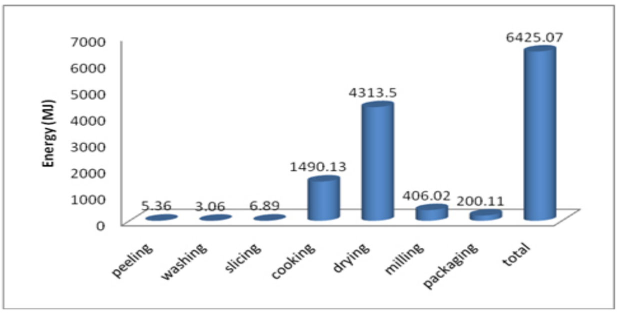

Figure 1. Energy utilization pattern

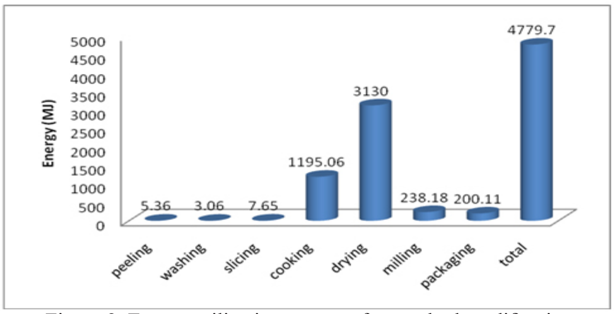

Figure 2. Energy utilization pattern after method modification

0.07, 0.04, 0.09, 22.94, 66.33, 7.04 and 3.48% of the total energy input were consumed by peeling, washing, slicing, cooking, drying, milling and packaging operations respectively.

The energy utilization of the instant-pounded yam flour production showed that drying consumed more than half of the total energy requirements. Similar observation was reported on production of milk powder (Ramirez *et al*., 2006). Drying as a unit operation consumes large proportion of energy in food processing (Singh, 1986).

Effect of sliced yam size on energy demand

Variation in thickness and shape of sliced yam did not affect magnitude of energy required for peeling, washing, and packaging. However, slight increase in percentage distribution was recorded. Percentage of energy input for peeling, washing and packaging increased from 0.07%, 0.04%, and 3.48% to 0.10%, 0.06% and 4.68% respectively. The magnitude of energy utilization for slicing increased from 6.89MJ to 7.65MJ (Table 3). This was associated with more time requirement in achieving the desired yam shape and size. In addition, percentage proportion rose from

0.09% to 0.14%. The total energy utilization was reduced from 6425.07MJ to 4779.42MJ. Total energy conserved was 25.62%. Procedural and behavioral changes can save about 30% energy without capital investment (Fischer *et al*., 2007).

Magnitudes of the three most energy consuming operations reduced from 1490.13MJ, 4313.50MJ, and 406.02MJ to 1195.06 MJ, 3130MJ and 238.18MJ for cooking, drying, and milling respectively (Figure 2). These give differences of 295.07MJ, 1118.50MJ, and 167.84MJ, which are equivalents of 4.59%, 18.42%, and 2.61% reduction in energy used respectively. The specific energy consumption by air-drying systems varies significantly with operating parameters (Sarsavadia, 2007). These operating parameters include air velocity, temperature, relative humidity, fraction of air recycled and surface area of drying material. This theory explains 18.19% reduction in demand for drying. Further reduction might be possible if more parameters are varied.

Effect of electric motor efficiency on energy used

Changing electrical motor of power output efficiency from 65 to 85 in calculation reduced the energy requirements for milling and packaging by 2.05MJ and 0.17MJ respectively. This summed up to 2.22MJ, an amount of energy close to half of the magnitude used for peeling 1000 kg of yam. Power factor of electrical equipment is the fraction of the total amount of electrical equipment, which is effective in producing power. Most alternating current motors have a lagging power factor ranging from 0.5 to 0.9. Power factor of one is best (Aderemi *et al*., 2009).

Conclusions

Energy sources used in the production of instant-pounded yam flour are human, liquid fuel and electricity. Energy required to process 1000 kg of yam to instant-pounded yam flour was 6425.07 MJ. Drying (67.14%), cooking (23.19%) and milling (6.32%) were the three most energy consuming unit operations. Improvement of surface area of yam for cooking and drying, coupled with high efficient electric motor power output for milling, reduced the magnitudes of the energy requirements for cooking, drying and milling by 4.59%, 18.42%, and 2.60% respectively. Finding of the work revealed that it is possible to conserve energy during production of instant-pounded yam using procedural and behaviour approach.

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