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EXPENDING AND CONSERVING ENERGY IN POUNDED YAM FLOUR PRODUCTION

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Abstract: conducted using two approaches, namely: without process adjustment (Slice thickness ≤ 14 mm, parboiled for 25 minutes, dried at 60 °C) and with process adjustment (Slice thickness ≤ 5 mm, parboiled for 20 minutes, dried at 80 °C). Results revealed eight units of operation for instant pounded Yam flour production. Adjustments in production conditions; thickness of Yam slices, steaming time and drying temperature resulted in less production time with an energy reduction from 86.26 kWh at a cost of ₦2,618.70/day to 28.60 kWh at a cost of ₦ 868.15/day to give 67.00% decrease in energy consumption.

The ANOVA showed that process adjustment had a significant ($p < 0.05$) effect on the amount of energy consumed during the processing of instant pounded Yam flour.
Thermal processes namely; parboiling and drying were the most energy intensive while washing was the least energy intensive unit operation, thus energy assessment aided in cutting down losses while running an efficient instant pounded Yam flour processing operation.

Key words*: Yam, instant pounded Yam flour, unit operations, energy assessment, energy consumption, process adjustment, energy utilization*

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INTRODUCTION

Nigeria is acknowledged to be the largest producer of Yams in the world, yielding over 35.02 million metric tonnes in 2008 [1]. The protein content of Yam (*Dioscorea* spp.) surpasses that of other root and tubers [2], and Yam is used in the preparation of various traditional recipes in Nigeria, West Africa. Instant Pounded Yam Flour (IPYF) is the flour obtained after Yam tubers have been sliced, sulphited, parboiled, dried and milled. The flour when poured into a known volume of boiling water is mixed to form a dough comparable to that obtained from the customary and manually tasking "mortar and pestle" pounded Yam [3], which is a delicacy in Nigerian socio cultural events. The IPYF is preferred by the working class and the crème de la crème in Nigeria because of its ease and speed of preparation. Generally, the white Yam (*Dioscorea rotundata)* is preferred for the preparation of pounded Yam as can be observed in most eateries and important occasions in Nigeria.

The aim of Yam processing which includes, lessening of postharvest losses of fresh tubers, improvement of the taste of Yam products, and transformation of Yam from fresh solids to flour requires energy intensive operations. [4] reported that the approach used in the reduction of energy consumption is heat recovery, adjusting the operation conditions or to reduce heat loss with insulation. In agriculture, the best energy use is revealed in two ways, i.e. energy savings with no change in productivity or a growth in productivity using the current levels of the source of energy available [5]. Incessant black out coupled with increase in electricity tariff in Nigeria, West Africa are causes of concern for agro-food industries because an increase in energy cost will result in a concurrent increase in operating costs and invariably the cost of resulting products hence the need to save and manage energy effectively.

Studies are available on energy utilization for production of cocoa flour [6], wheat flour [7], instant pounded Yam flour with respect to Yam thickness and shape [8], instant pounded Yam flour by comparing cooking, steam and wet milling methods of preparation [7]. The purpose of this study was to quantify energy consumption from the national grid in processing IPYF at pilot scale in order to provide data for understanding energy expenditure, and also proffer solution to high cost of energy in processing of IPYF by adjusting the operating condition for proper management of energy.

MATERIAL AND METHODS

Investigations were conducted in a pilot plant of a medium sized organization located in southwestern Nigeria. Yam tubers were bought from the local Yam market, cleaned of extraneous material and weighed. The cleaned Yam tubers were manually peeled with stainless steel knives, manually washed with potable water and sliced using a mechanical slicer. The slices were sulphited (0.1 g / litre of water) for 30 minutes, precooked in a steaming machine and dried in a batch dryer. The dried Yam chips were milled, allowed to cool and sealed in low density polythene packs.

All unit operations were timed with a digital timer. Based on energy supplied from the national grid, two approaches for energy assessment of IPYF production were used namely; (a) Without process adjustment (b) With process adjustment.

The energy resources used in the production of IPYF including the number of persons per operation, the power ratings of each machine used and time required for operation were recorded. Data obtained were inputted in available energy equations as described below.

Without process adjustment

Ten kilogram of Yam tubers were peeled, washed and mechanically sliced. The total output of Yam slices (thickness ≤ 14 mm) from the mechanical slicer were sulphited for 30 minutes, cooked for 25 minutes using steam, dried at a temperature of 60 °C [9] to ≤ 14.5 % moisture content wet basis, milled and packaged.

With process adjustment

Ten kilogram of Yam tubers were peeled, washed and mechanically sliced. The Yam slices from the mechanical slicer (thickness ≤ 5 mm) excluding the discolored head region were sulphited for 30 minutes, cooked for 20 minutes using steam, dried at a temperature of 80 °C to ≤ 14.5 % moisture content wet basis, milled and packaged.

Energy consumption of IPYF production line

Using the data collected from the IPYF production line, the energy consumption during production was determined based on an 8-hour working day, according to Equations (1 to 9) by [10] as follows:

$$E_{pl} = (0.075 \times N_{pl} \times t_{pl}) \quad (1)$$
$$E_{w} = (0.075 \times N_{w} \times t_{w}) \quad (2)$$
$$E_{s} = [(0.075 \times N_{s} \times t_{s}) + (\eta \times P_{s} \times t_{s})] \quad (3)$$
$$E_{sul} = (0.075 \times N_{sul} \times t_{sul}) \quad (4)$$
$$E_{pb} = [0.075 \times N_{pb} \times t_{pb}) + (W_{pb} \times C)] \quad (5)$$
$$E_{d} = [(0.075 \times N_{d} \times t_{d}) + (\eta \times P_{d} \times t_{d})] \quad (6)$$
$$E_{m} = [(0.075 \times N_{m} \times t_{m}) + (\eta \times P_{m} \times t_{m})] \quad (7)$$
$$E_{pk} = [\left(0.075 \times N_{pk} \times t_{pk}\right) + (\eta \times P_{pk} \times t_{pk})] \quad (8)$$
$$E_{T} = E_{pl} + E_{w} + E_{s} + E_{sul} + E_{pb} + E_{d} + E_{m} + E_{pk} \quad (9)$$

Where: E is energy and subscripts (pl, w, s, sul, pb, d, m, and pk) are used to indicate the particular unit operation, for which energy estimate will be carried out, i.e. peeling, washing, slicing, sulphiting, parboiling, drying, milling and packaging respectively.

N is the number of persons involved in a unit operation.
t is the time to complete a unit operation (h).
The average power output a human being in the tropics will sustain for an 8 - 10 hour workday is 0.075 kW [11].
η is 80% being the efficiency for electric motor of the machine [12].

W is the quantity of fuel used (kg).
C is 45.5 MJ/kg (12.64 kW/kg) being heating value of cooking gas (LPG) [13].
P is rated power for a particular unit operation (kW).
E_T is total quantity of energy (kWh).
Conversion factor for electrical energy is 1 kWh = 3.6 MJ [6].
Nigeria electricity tariff is ₦30.36/ kWh [14].

Statistical analysis

The experimental data (total energy consumption) was inputted for Analysis of Variance (ANOVA) using general linear model and means were compared using Tukey test. Statistical analysis ($p \leq 0.05$) was carried out by means of Minitab 17 software at two levels of process adjustment (with process adjustment and without process adjustment) in seven replicates.

RESULTS AND DISCUSSION

Table 1 shows that manual, electrical and thermal energy were involved in the processing of IPYF. Drying and parboiling were estimated to be 5.21 and 80.92 kWh respectively without process adjustment and 4.20 and 24.28 kWh respectively with process adjustment, however washing was 0.004 kWh for both processes.

Table 1. Parameters used for estimation of energy values for IPYF production

S/N	Unit operation	Required parameter	Value
1	Peeling	Manual power (kW)	0.075±0.00
		Time taken (hr)	0.036±0.012
		Number of persons involved	1±0.00
2	Washing	Manual power (kW)	0.075±0.00
		Time taken (hr)	0.005±0.00
		Number of persons involved	1±0.00
3	Slicing	Manual power (kW)	0.075±0.00
		Electrical power (kW)	1.5±0.00
		Time taken (hr)	0.0059±0.001(0.0071±0.002)
		Number of persons involved	1±0.00
4	Sulphiting	Manual power (kW)	0.075±0.00
		Time taken (hr)	0.5±0.00
		Number of persons involved	1±0.00
5	Parboiling	Manual power (kW)	0.075±0.00
		Calorific value of fuel used (MJ/kg)	45.5 (12.64 kWh/kg)
		Quantity of fuel used (kg)	0.41±0.09 (0.33±0.05)
		Time taken (hr)	0.42±0.00 (0.33±0.00)
		Number of persons involved	1±0.00
6	Drying	Manual power (kW)	0.075±0.00

		Cont. Table 1.	
		Electrical power (kW)	4.87±0.00
		Total time taken (hr)	20±0.00 (6±0.00)
		Number of persons involved	2±0.00
7	Milling	Manual power (kW)	0.075±0.00
		Electrical power (kW)	2.2±0.00
		Time taken (hr)	0.034±0.001
		Number of persons involved	1±0.00
8	Packaging	Manual power (kW)	0.075±0.00
		Electrical power (kW)	0.4±0.00
		Time taken (hr)	0.0173±0.00
		Number of persons involved	1±0.00

Note: Bold font indicates with process adjustment where different (Mean ± Std Dev)

The total energy used for IPYF production without process adjustments was estimated to be 86.26 kWh at a cost of ₦2,618.70/day (Tab. 2) at a total operating time of 21 hours attaining dried Yam chips (≤ 14.5% moisture content wet basis) and IPYF (≤ 10% w.b) beyond the operating time of the pilot plant (8 hours).

Table 2. Estimates of energy use pattern for IPYF production without process adjustment

S/N	UNIT OPERATION	POWER INPUT	ENERGY VALUE (kW)	NO. OF PERSONS	TIME TAKEN (hrs.)	60 °C ENERGY (kWh)
1	Peeling	Manual	0.075	1	0.0356	0.0030
2	Washing	Manual	0.075	1	0.0050	0.0004
3	Slicing	Electrical	1.5	1	0.0059	0.0075
4	Sulfiting	Manual	0.075	1	0.5000	0.0375
5	Parboiling	Thermal	12.64	1	0.4200	5.2139
6	Drying	Electrical	4.87	2	20.000	80.9200
7	Milling	Electrical	2.2	1	0.0340	0.0624
8	Packaging	Electrical	0.4	1	0.0173	0.0082
	Total energy consumption (kWh)					86.2551
	Energy costs (₦)/day					2,618.7042

Table 3 reveals that the total energy used for IPYF production with process adjustment was estimated to be 28.60 kWh at a cost of ₦ 868.15/day at a total operating time of 7 hours, attaining dried Yam chips (≤ 14.5% moisture content wet basis) and IPYF (≤ 10% w.b) within the operating time of the pilot plant (8 hours). The ANOVA showed that the effect of process adjustment was significant ($p \leq 0.05$) on energy consumption, also the Tukey test for comparison of means showed that the process used for IPYF preparation are significantly different ($p \leq 0.05$).

Table 3: Estimates of energy use pattern for IPYF production with process adjustment

S/N	UNIT OPERATION	POWER INPUT	ENERGY VALUE (kW)	NO. OF PER-SONS	TIME TAKEN (hrs.)	80 ºC ENERGY (kWh)
1	Peeling	Manual	0.075	1	0.0356	0.0030
2	Washing	Manual	0.075	1	0.0050	0.0004
3	Slicing	Electrical	1.5	1	0.0071	0.0091
4	Sulfiting	Manual	0.075	1	0.5000	0.0375
5	Parboiling	Thermal	12.64	1	0.3300	4.1960
6	Drying	Electrical	4.87	2	6.0000	24.2760
7	Milling	Electrical	2.2	1	0.0340	0.0624
8	Packaging	Electrical	0.4	1	0.1730	0.0082
	Total energy consumption (kWh)					28.5952
	Energy costs (₦/day)					**868.1489**

Analysis of Variance

Source	DF	Adj SS	Adj MS	F-Value	P-Value
Process adjustment	1	11672.9	11672.9	13953.45	0.000
Error	12	10.0	0.8		
Total	13	11683.0			

Tukey Pairwise Comparisons

Grouping Information Using the Tukey Method and 95% Confidence

Process adjustment	N	Mean	Grouping
Without process adjustment	7	86.327	A
With process adjustment	7	28.577	B

*Means that do not share a letter are significantly different.

Eight units of operation were involved in the processing of IPYF, manual energy was used in all stages of production for either method of production and the energy intensive operations were identified as drying and parboiling while washing was non energy intensive for both methods used in this study.

Drying consumed more than half of the total energy requirements for both approaches. A similar observation on high energy consumption during drying was reported by [7] for instant pounded Yam flour production. Washing (cleaning) was the least energy intensive operation, this may be due to simplicity of the process as similarly reported by [6] for cocoa flour processing. Total energy consumption for IPYF production without process adjustment exceeded that with process adjustment by 57.66 kWh surpassing it by 67.00%.

The high energy cost for IPYF production without process adjustments may be due to high thickness of Yam slices and low drying temperature resulting in long drying time. Conversely, the low energy cost for IPYF production with process adjustments showed a reduction with thinner Yam slices at higher temperature while attaining shorter drying duration. Observations in this study agrees with report of [15] that thinner pumpkin slices dry faster than thicker slices because the internal moisture had less distance to travel resulting in an increase in drying rate and the reports of [16] for convective drying of apple slices which showed that an increase in air temperature reduces the drying time and increases the drying rate. The ANOVA results show that energy consumption increased without process adjustment and decreased with process adjustment implying that the effect of process adjustment was significant on energy consumption during IPYF processing.

CONCLUSIONS

It was found that eight unit of operations are required for IPYF production. Manual, electrical and thermal energy were the major sources of energy input in the production of IPYF. Total energy consumption without process adjustments exceeded that with process adjustments by 57.66 kWh.

The total energy consumption decreased by 67.00%, with increase in drying temperature and a decrease in thickness of Yam slices resulting in a decrease in total operating time for IPYF production with process adjustment. With the aid of a proper energy audit, the Yam processing industry can profit greatly with process adjustment as this translates to a reduction in energy consumption and inevitably production cost. Other methods of energy savings during IPYF preparation needs to be carried out for further studies as cooking gas prices have more than doubled and energy tariffs have also been increased since the period of this study.

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APPENDIX 1

Statistical analysis

General Linear Model: Energy consumption (kWh) versus Process adjustment

Method
Factor coding (-1, 0, +1)

Factor Information

Factor	Type	Levels	Values
Process adjustment	Fixed	2	With process adjustment, Without process adjustment

Analysis of Variance

Source	DF	Adj SS	Adj MS	F-Value	P-Value
Process adjust.	1	11672.9	11672.9	13953.45	0.000
Error	12	10.0	0.8		
Total	13	11683.0			

Model Summary

S	R-sq	R-sq(adj)	R-sq(pred)
0.914637	99.91%	99.91%	99.88%

Coefficients

Term	Coef	SE Coef	T-Value	P-Value	VIF
Constant	57.452	0.244	235.03	0.000	

Process adjustment
With process adjustment -28.875 0.244 -118.12 0.000 1.00
Regression Equation

Energy consumption (kWh) = 57.452 - 28.875 Process adjustment_With process adjustment + 28.875 Process adjustment_Without process adjustment

Tukey Pairwise Comparisons

Grouping Information Using the Tukey Method and 95% Confidence

Process adjustment	N	Mean	Grouping
Without process adjustment	7	86.327	A
With process adjustment	7	28.577	B

Means that do not share a letter are significantly different.

Tukey Simultaneous 95% CIs

POTROŠNJA I OČUVANJE ENERGIJE U PROIZVODNJI YAM (*Dioscorea rotundata)* BRAŠNA

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Apstrakt: Istraživanje je provedeno korišćenjem dva pristupa, i to:
bez prilagođavanja procesa (debljina preseka kriški je ≤ 14 mm, prokuvano 25 minuta, sušeno na 60 °C);
sa podešavanjem procesa (debljina preseka kriški je ≤ 5 mm, prokuvano 20 minuta, sušeno na 80 °C).
Rezultati su pokazali osam jedinica (uzoraka) za instant proizvodnju mlevenog Yam brašna.

Prilagođavanja uslova proizvodnje; debljina Yam kriški, vreme prokuvavanja i temperatura sušenja rezultirali su kraćim vremenom proizvodnje sa smanjenjem energije sa 86,26 kWh po ceni 2,618,70 ₦/dan na novu vrednost od 28,60 kWh po ceni 868,15 ₦/dan, što je dovelo do smanjenja potrošnje energije za 67,00%.
Analiza ANOVA pokazuje da prilagođavanje procesa ima značajan (p <0,05) uticaj na količinu energije potrošene tokom prerade instant mlevenog brašna.
Toplotni procesi kao što je prokuvavanje i sušenje su energetski najzahtevniji, dok je pranje uzoraka bilo najmanje energetski intenzivan .
Procena utrošene energije je pomogla u smanjenju gubitaka tokom efikasne operacije prerade instant mlevenog Yam brašna.

Ključne reči: *Yam, instant mleveno yam brašno, jedinica procesa , procena energije, potrošnja energije, prilagođavanje procesa, korišćenje energije*

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