

## Investigation of Energy Efficiency in the Use of a Flash Dryer for Production of Quality Instant Pounded Yam Flour

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### ABSTRACT

Drying is an important unit operation in the production of Instant Pounded Yam Flour (IPYF). Flash drying has advantages over other conventional dryers as it operates at high temperature (up to 200°C) and dries products within a short period of time. However, thermal efficiency and rate of heat loss of flash dryers are still of concern especially for production of quality flour from yam mash. This study was therefore designed to investigate the drying duration, rate of heat losses and energy use in a single cyclone flash dryer for production of high quality IPYF. Fresh and dry yam samples (freshly harvested (FH) and stored tubers (ST)) at 72 and 59% moisture content (wet basis), respectively, were used for the study. Experimental studies were carried out by drying 16.00 kg each of stored and fresh yam mash in a single cyclone flash dryer. The dryer, powered by spent oil, was fitted with sensors along the duct to measure temperature and air flow rate. Drying time was also noted to compare with other conventional dryers. The throughput capacity and operational parameters such as enthalpy, specific heat capacity, heat losses and energy efficiency of the flash dryer were determined using standard methods. The physicochemical properties of IPYF were determined. Data were analyzed using ANOVA at  $\alpha_{0.05}$ . The highest drying temperature was 125°C for stored yam samples and 150°C for fresh yam samples, respectively. Maximum drying durations were recorded to be 13 and 32 minutes for stored and freshly harvested yam samples, respectively. This was lesser to 38 minutes recorded in literatures for conventional dryers. The throughput capacity, enthalpy (ambient, inlet and outlet), power input, specific heat capacity, energy efficiency of the experimental dryer were obtained as 227.4 kg/h, (73.492, 228 and 185.63 kJ/kg), respectively; 2101.32 kJ/h; 4791.10 kJ/kg°C; 27.8 and 30.6% (for stored and freshly harvested yam, respectively). Thermal energy and specific heat losses were obtained as 8.8 MJ, 88.9 MJ/h and 14.0 MJ, 89.0 MJ/h for stored and freshly harvested, respectively. These indicate the need for the dryer insulation to minimize heat loss. The physicochemical properties were 2.45, 2.6, 0.55, 92.3 and 3.8% for crude protein, crude fibre, ether extract, carbohydrate and ash contents for freshly harvested yam samples, while, 36.83, 26.80, 71.20, 71.80 and 86.44% were obtained for amylopectin, viscosity, paste clarity, pasting temperature and dispersibility and 0.42, 0.54, 1.73, 0.95 and 18.60 g/mol were obtained for loose, packed bulk densities, water, oil absorption capacities and swelling power for stored yam samples, respectively. The study established that the flash dryer saves operational time, although, its energy consumption is high amidst low energy efficiency, underscoring need for insulation and reduced usage of spent oil. However, high operational temperature notwithstanding, nutritional qualities of the flour met the Food and Agricultural Organization standards for Instant Pounded Yam Flour.

**Keywords:** Drying, Nutritional quality, Thermal efficiency, Insulation

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## 1. INTRODUCTION

Yam is one of the common names among tuber crop in the genus *Dioscorea*. It is basically cultivated for consumption, making money and as planting material among other benefits. The tuber is a good source of energy as its composition is about 23% carbohydrate. There are varieties of yam tuber, but very few ones are important, either for consumption or for economic reasons. Yam tuber is mostly found in all the geo-political zones in Nigeria where it serves as a major product in the daily food consumption except the southern part. The production of yam was recorded at about 47 million metric tonnes with Nigeria being the largest producer of about 70% of the total world population (FAO, 2015). However, the consumption of yams (and other root crops) is immeasurable today, which makes their protein contribution very significant. Furthermore, noticeable amount of vitamins and minerals are what most root crops are composed with competitive production advantage in terms of energy yield per hectare over cereals produced in ecologically different conditions. Other nutritional requirements of yam tuber include more of vitamins and minerals such as phosphorus and potassium as compared to potatoes, although the latter are richer in vitamins A and C. Due to comparative advantage of white yam over other types of yam species in terms of marking value and consumption, its cultivation therefore serves as a motivation to farmers to go into its production due to its value addition and that it is regarded as the best yam both in terms of consumption and profit making.

Meanwhile, factors such as weak infrastructure, poor transport system, lack of suitable storage facilities and the perishable nature of freshly harvested yam tubers make farmers not to get enough value for their product (Ndukwu, 2011). This result to great losses especially following the period after harvest from the field. The challenges which result due to improper storage system include the physiological activities such as sprouting, transpiration and respiration which all depend on the temperature and relative humidity of the environment where the product is stored. To curb the challenges of losses, freshly harvested tubers are processed into various storable form in order to extend its shelf life, making the activities of spoilage organs inactive or dormant, thereby making yam products available throughout the year. Such storable form include, instant pounded yam flour (*Iyan*), chips, yam flour (*elubo*), among other products. The processing method of this product is of importance especially those that require high drying temperature, such that the nutritional composition of the product is not tempered with nor affected, hence, retained at its peak and not affected by high temperature of drying. It is the aim of this study to access the energy required in the use of the flash dryer for the production of quality yam flour

### 1.1 Objective of the study

This study was designed to investigate the drying duration, rate of heat losses and energy use in a flash dryer for production of quality IPYF

## 2. MATERIALS AND METHOD

### 2.1 Materials

The flash dryer used for the experimental method is a single cyclone dryer with capacity of about 227.4kg/hr. The performance of the dryer in terms of thermal efficiency, energy consumption, heat losses, among others was assessed when used for the production of Instant Pounded Yam Flour. The dryer section was composed of a heating unit, a drying duct and a separator, while the heating unit included a burner and a double-pipe heat exchanger. The energy source of the dryer is the mixture of petrol and black oil in the ratio 1:4. Figure 1 shows the layout of operational principle of a typical flash dryer system.

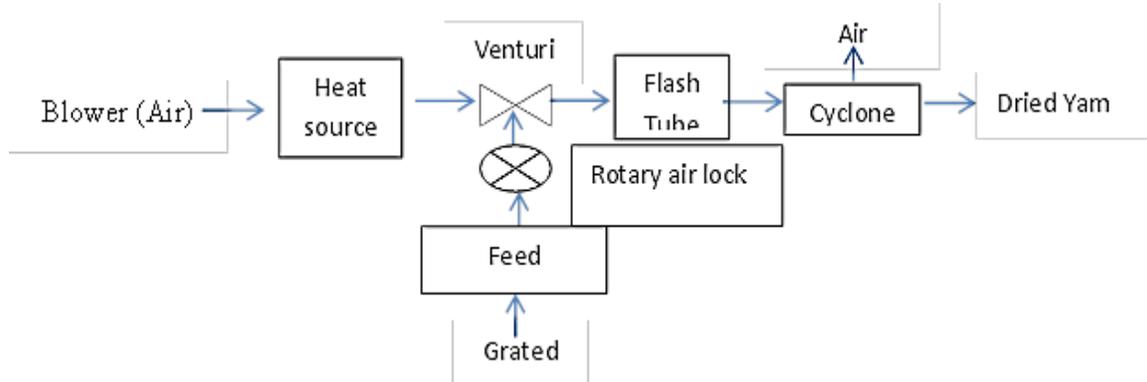


Fig. 1: Block Diagram of the Flash Dryer System

Source: Kuye et al., 2017

### 2.1.1 Raw Materials for Instant Pounded Yam Flour

The raw materials used in the production of instant pounded yam flour were matured freshly harvested (FH) and stored yam (ST) tubers, from South West Nigeria. The tubers were bought at a local market in Ekiti State, Nigeria because most IPYF in the market are not from this region

## 2.2 Experimental methods

### 2.2.1 Preparation of the Samples for Drying Operation in a Flash Dryer

Two yam samples, freshly harvested and stored yam tubers of the same variety (white yam (*Dioscoreae rotundata*)) with initial moisture content of about 72% and 59% respectively were used for the experiment. Each of the two samples was weighed to twenty-eight and half kilogrammes (28.5 kg) and were used for the experiments. Two graters of particle sizes 3.5 $\mu$ m and 4.5 $\mu$ m were used for the size reduction of each of the samples.

The experiment was carried out in a processing company at Ota, Ogun State of Nigeria. The production process of IPYF entails the simple operation as shown in Figure 2. The fresh tubers of 28.5kg weight were thoroughly washed with clean water to remove sand and other dirt, manually peeled, sliced into circular pieces of 3cm - 5cm thickness with a sharp stainless kitchen knife in a water bath to prevent dis-colouration of the tubers. The samples were blanched at 100°C for 36 minutes, cooled for 60 minutes before size reduction process. The particle size of the samples were reduced using 4.5  $\mu$ m and 3.5  $\mu$ m hole sieve sizes, denoted as G<sub>1</sub> and G<sub>2</sub> respectively. Both samples were subjected to the same processing methods. Plates 1, 2, 3 and 4 show the processing steps of raw yam tuber for IPYF production.



**Plate 1.** Washing of the yam tubers with clean water



**Plate 2.** Sliced tubers in the water bath



**Plate 3.** Setting the yam tubers for blanching



**Plate 4.** The grater used for grating the yam sample

### 2.2.2 Procedure for Drying Operation

The flash dryer used was a single cyclone, pre-heated to a temperature of about 175°C in order to ensure stability of the condition of the dryer to that of the wet sample before loading (i.e. feeding) of the samples into the dryer. Samples were fed into inlet of pre-heated dryer as shown in Plate 5a and was immediately sent to travel through the stream of hot air which was provided in the combustion chamber within the dryer in order to dry the product. The dryer was operated with sensors at strategic points to measure temperature, air flow rate, thermal efficiency, specific heat consumption, among other ambient values. The dried product was separated from the hot air as it passes through the cyclone and was collected with a clean bowl as shown in Plate 5b. However, fresh yam sample was back-mixed during drying due to its high initial moisture content.

This was done to aid the drying process (Richard, 2010). The same experimental procedure was carried out for stored yam sample and labeled as  $G_1$  and  $G_2$  for  $4.5 \mu\text{m}$  and  $3.5 \mu\text{m}$  grater sizes respectively. Plate 6a and 6b shows the milling of IPYF after drying in a flash dryer and packaged in a moisture proof bag respectively.



**Plate 5a.** Loading of the sample into the dryer



**Plate 5b.** Exit of the dry sample



**Plate 6.** Milling of the flour (IPYF)



**Plate 7.** IPYF sample in a moisture proof bag



## 2.3 Determination of some Operational Properties of flash dryer for Dryer Performance

### 2.3.1 Determination of Enthalpy of the ambient air ( $h_{amb}$ )

This was determined from the air property relations as stated by Igbeka, 2013 using equation 1

$$h_{amb} = C_p T_{amb} + \omega_1 h g_1 = C_p T_{amb} + \omega_1 (h_w + C_{P_w} \cdot T_{amb}) \quad (1)$$

### 2.3.2 Determination of the Enthalpy ( $h_{in}$ ) of the inlet air into the dryer

This was evaluated using equation (1) as stated by Igbeka, 2013

$$h_{in} = C_p T_{in} + \omega_1 h g_1 = C_p T_{in} + \omega_1 (h_w + C_{P_w} \cdot T_{in})$$

### 2.3.3 Determination of the Enthalpy ( $h_{out}$ ) outlet air of the dryer

This was evaluated using equation (1) as given by Igbeka, 2013

$$h_{in} = C_p T_{out} + \omega_1 h g_1 = C_p T_{out} + \omega_1 (h_w + C_{P_w} \cdot T_{out})$$

### 2.3.4. Determination of Air volume flow ( $m^3/s$ )

This was evaluated from the area of the product of the outlet channel or the cross-sectional area of the drying duct (cylindrical) and the air velocity as stated by Strumiłło *et al.* (2014)

$$A = \frac{\pi d^2}{4} \quad (2)$$

where A = area;  $m^2$ , d = diameter of the outlet channel; m

### 2.3.5 Determination of Air mass flow, $A_m$ (kg/s)

This was evaluated using equation (4) as suggested by Strumiłło *et al.* (2014)

$$A_m = \rho \times V \quad (3)$$

where  $A_m$  = Air mass flow; kg/h,  $\rho$  = Air density; kg/  $m^3$  and V = Specific volume;  $m^3/s$

### 2.4.6. Determination of Power Input or Energy Rate into the dryer

This was evaluated using equation (4) as suggested by Strumiłło *et al.* (2014)

$$E = h \times A_m \quad (4)$$

Where E = Energy rate (kJ/h),  $h_{in}$  = enthalpy of inlet air (kJ/kg dry air),  $A_m$  = Air mass flow (kg/h)

### 2.4.7. Determination of Specific Heat Consumption, $q_s$

**Specific energy consumption ( $q_s$ )** was calculated according to Kudra (2009) based on the heat rate added by the dryer's heating unit to the ambient air ( $\Delta Q_{in}$ ) and the water evaporation rate ( $\dot{m}_w$ ) as shown in Equation 5.

$$q = \frac{Q_{\Delta}}{m_{\vartheta}} = \frac{A_m(h_{in} - h_{amb})}{m_{dm}(X_{wp} - X_{dp})} \quad (5)$$

where:

$A_m$  is the air mass flow rate and  $h_{in}$ ,  $h_{amb}$  are the enthalpy of inlet and ambient air respectively. The value for  $A_m$  was calculated from the air density, air velocity and cross-sectional area of the exhaust air.

$$\text{Energy efficiency}(\eta_e) = \frac{Q_w}{Q_{\Delta}} = \frac{m_{\vartheta} \cdot \lambda}{Q_{\Delta}} = \frac{m_{dm}(X_{wp} - X_{dp}) \cdot \lambda}{A_m(h_{in} - h_{amb})} \quad (6)$$

#### 2.4.8. Determination of Thermal efficiency of the dryer, $\eta_T$

**Thermal efficiency, ( $\eta_T$ )**, was defined according to Strumillo *et al.* (2014) based on the inlet air temperature ( $T_{in}$ ), the outlet air temperature ( $T_{out}$ ) and the ambient temperature ( $T_{amb}$ ), as shown in Equation 7.

$$\eta_T = \frac{T_{in} - T_{out}}{T_{in} - T_{amb}} \quad (7)$$

#### 2.4.9. Determination of Heat losses to the ambient, $Q_{amb}$

Heat losses to the ambient,  $Q_{amb}$  (kJ/h), consists of radiation and convection heat losses which were determined from the dryer's energy balance, as suggested by Rotstein and Crapiste (1997). This calculation took into consideration the heat input rate into the dryer  $Q_{in}$  (kJ/h), the energy input rate of the wet product,  $Q_{wp}$  (kJ/h), the heat output rate from the exhaust air,  $Q_{out}$  (kJ/h), and the energy output of the dried product,  $Q_{dp}$  (kJ/h), is as shown in Equation 8.

$$Q_{amb} = (Q_{in} + Q_{wp}) - (Q_{out} - Q_{dp}) = (h_{in} \cdot \dot{m}_{air} + h_{wp} \cdot m_{dm}) \quad (8)$$

where  $h_{out}$  (kJ/kg<sub>dry air</sub>) is the specific enthalpy of the exhaust air,  $h_{wp}$  (kJ/kg<sub>dm</sub>) is the specific enthalpy of the wet product and  $h_{dp}$  (kJ/kg<sub>dm</sub>) is the specific enthalpy of the dried product. The value for  $h_{out}$  was calculated from  $T_{out}$  and  $\phi_{out}$ . The values for  $h_{wp}$  and  $h_{dp}$  were calculated from the product temperature and Cp (kJ/kg<sub>dm</sub>·°K).

### 2.3 Determination of Physico-Chemical Properties of IPYF

The physico-chemical properties of the samples were determined at the Anatomy Laboratory Department of University of Ibadan, Ibadan. Properties such as moisture content, ash, crude fibre, crude fat, crude protein and carbohydrate were determined by the method of *Apranita et al.* (2014) and AOAC (1990) while, the carbohydrate contents of the samples were estimated using;

$$\% \text{ Carbohydrate} = \{100 - \% (MC+A+F+CF+CP)\} \% \quad (9)$$

where: MC, A, F, CF and CP were percentages of moisture content, ash, fat, crude fibre and crude protein contents respectively.

### 2.4 Determination of physical properties

Pasting characteristics of the IPYF samples was determined with a Rapid Visco Analyser (RVA) as described by Adebowale *et al.* (2008). The standard deviation (S.D.) of the physical properties were determined from Equation (10). This was done to measure the variation of the set of data.

$$\text{S.D.} = \sqrt{\sigma} \quad (10)$$

where S.D. is the standard deviation,  
 $\sigma$  is the variance

## 2.5 Determination of Functional property parameters

Bulk density was determined using the method of Chau and Cheung (1997).

Density of a material can be calculated from the expression in Equation (11)

$$\rho = \frac{w_s}{V_C} \quad (11)$$

The Water and Oil absorption capacities (WAC and OAC) of IPYF samples were determined by the modified method of Phillips *et al.* (2012).

## 2.6 Determination of colour

The colour of IPYF samples were measured with a Minolta CR-310 (Minolta camera Co. Ltd, Osaka, Japan) tristimulus colorimeter, recording  $L^*$ ,  $a^*$  and  $b^*$  values.  $L^*$  represented lightness (with 0= darkness/blackness to 100= perfect/brightness);  $a^*$  corresponds to the extent of green colour (in the range from negative= green to positive = redness);  $b^*$  represents blue in the range from negative=blue to positive=yellow.

## 2.7 Chemical Laboratory Analysis

The effect of particle size, drying temperature and blanching parameters on the nutritional quality of dried product were evaluated by subjecting the processed product to proximate analysis. The proximate analysis is the assessment of some functional properties of the sample as affected by the aforementioned parameters.

## 2.8 Statistical Analysis

Quadratic programming (non-linear multiple regression programming) was formulated and used to solve the Equation using ANOVA 2010 package for the assessment of proximate analysis to determine the level at which the parameters were affected by the functional properties of the IPYF sample produced (if any). Meanwhile, Rangaswamy (2010) stated that, multiple regression equation (as shown in the equation that follows) can be used to solve the process model. Excel solver was used to solve the problem.

$$Y = b_0 + b_1x_1 + b_2x_2 \quad (12)$$

Where Y= food nutrition parameters as dependent variables resulting from the combination of the independent variables.  $b_0, b_1, b_2$  = regression coefficients

$x_1, x_2$ = independent variables (such as moisture content and particle size respectively). The analysis of variance (ANOVA) of multiple regressions was carried out using the Excel Solver.

## 3. RESULTS AND DISCUSSION

### 3.1 Flash Dryer Performance for Drying of Instant Pounded Yam Flour

The following parameters were used for the assessment of the performance evaluation of the flash dryer that was used for IPYF production

#### 3.1.1 Absolute humidity, $\omega$

The following parameters were obtained by measurements; Relative humidity (RH amb,  $\phi$ ) = 56.5 %, P (amb) = 1010.086 hPa = 101008.6 Pa,  $P_{sv}$  = saturation vapour pressure = 4601.8 Pa. This was determined through interpolation (see Appendix A-1) using air property table).

The absolute humidity of the drying tube was therefore obtained as 0.1643 kg H<sub>2</sub>O/kg dry air using Equation 1. where, relative humidity (RH amb),  $\phi$  = 56.5 %, P (amb) = 1010.086 hPa = 101008.6 Pa

#### 3.1.2 Enthalpy of the ambient air ( $h_{amb}$ )

This was obtained from Equation (2) as  $h_{amb} = 73.492$  kJ/kg

where:  $T_{amb} = 31.3$  °C,  $CP_w = 1.82$  kJ/kg°C,  $C_p = 1.005$  kJ/kg°C,  $h_w$  at 0°C = 2500.9 kJ/Kg and  $\omega = 0.1643$  kg H<sub>2</sub>O/kg dry air

#### 3.1.3 Enthalpy ( $h_{in}$ ) of inlet air into the dryer, ( $h_{in}$ )

This was obtained from Equation (2) as 228 kJ/kg dry air Using  $C_p = 1.005$  kJ/kg°C,  $T_{in} = 105$ °C,  $h_w$  at 0°C = 2500.9 kJ/kg and  $CP_w = 1.82$   
where  $\omega_1$  = absolute humidity = 0.0456 kg H<sub>2</sub>O/kg dry air (using Equation 1)

#### Enthalpy ( $h_{out}$ ) of outlet air of the dryer ( $h_{out}$ )

This was evaluated using Equation (2) and obtained as 185.63 kJ/kg dry air

where,  $CP_w = 1.82$ ,  $C_p = 1.005$  kJ/kg°C,  $h_w$  at 0°C = 2500.9 kJ/Kg and  $T_{out} = 65.8$  °C, absolute humidity,  $\omega_1 = 0.0456$  kg H<sub>2</sub>O/kg dry air ( $\omega_1$  is constant for drying process in the dryer)

#### 3.1.4 Air mass flow (kg/s)

This was evaluated using equation (4) and obtained as  $A_m = 0.5837$  kg/s = 2101.32 kg/h

where  $\rho$  = Air density = 1.2 kg/ m<sup>3</sup> and V = Specific volume = 0.4865 m<sup>3</sup>/s

#### 3.1.5 Power input or Energy rate into the dryer, E

This was evaluated using Equation (5) and obtained as 133.084 kJ/s = 479100.96 kJ/h

where, enthalpy of the inlet air,  $h_{in} = 228$  kJ/kg dry air,  
 $A_m$  = Air mass flow = 0.5837 kg/s = 2101.32 kg/h

#### 3.1.6 Specific Heat Consumption, ( $q_s$ ), of the product from the dryer

Specific energy consumption was evaluated from Equation (5) and obtained as represented in Table 1:

**Table 1: Values of the Specific Heat Consumption, ( $q_s$ )**

Sample	$q_s$	$h_{amb}$	$h_{in}$	$m_{dm}$	$A_m$	$X_{wp}$	$X_{dp}$
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Product	(MJ/kg)	(kJ /kg)	(kJ /kg)	(kg /h)	(kg /h)	(%)	(%)
G <sub>1</sub> (Dry yam)	8.7	73.49	228	31.43	2101.32	1.439	0.247
G <sub>2</sub> (Dry yam)	8.8	73.49	228	30.75	2101.32	1.439	0.239
G <sub>1</sub> (Fresh yam)	7.9	73.49	228	17	2101.49	2.571	0.146
G <sub>2</sub> (Fresh yam)	14.0	73.49	228	9.58	2101.49	2.571	0.157

From Table 1, the values obtained for the specific heat capacity of dry yam samples implies that 8.7 MJ and 8.8 MJ of energy obtained were used for every 1 kilogram each of the two samples (i.e. samples 1 and 2) respectively. Also, the specific heat consumption for the fresh yam (sample 2) was obtained as 14.0 MJ which was almost twice the value of sample 1 (with value 7.9 MJ of energy). This shows that more energy was used in removing moisture from G<sub>2</sub> (i.e. 3.5  $\mu\text{m}$ ) more than G<sub>1</sub> (4.5  $\mu\text{m}$ ) sample. This may be due to the high amount of moisture contained in G<sub>2</sub> which is more than the 4.5  $\mu\text{m}$  sample. The values of the specific heat capacity decreased with increase in temperature of drying. The same observation was reported by Ajala *et al.* (2014) which stated that there is a direct relationship between moisture content and specific heat capacity. The earlier report of Ajala *et al.* (2012) showed that temperature of drying has inverse relationship with moisture content of the samples, therefore, it could be inferred that as the temperature of drying increased, the value of specific heat capacity decreased because moisture content decreased. Also, Sopa *et al.* (2008) suggested that decrease in specific heat capacity affected by higher temperature might possibly be due to the increase in volume occupied by cassava starch granules, thereby reducing free moisture transfer within the starch granules.

### 3.1.7 Energy Efficiency, $\eta_e$ of the dryer

Energy efficiency ( $\eta_e$ ) was evaluated according to Kudra (2009) and calculated by dividing the heat used for water evaporation by the heat added to the ambient air by the dryer's heating unit ( $\Delta Q$ ) as shown in equation (6). This was obtained as:

Energy efficiency ( $\eta_e$ ) = 0.2784 = 27.8 % (for sample 1 dry yam)

Energy efficiency ( $\eta_e$ ) = 0.2742 = 27.4 % (for sample 2 dry yam)

Energy efficiency ( $\eta_e$ ) = 0.30634 = 30.6 % (for sample 1 fresh yam)

Energy efficiency ( $\eta_e$ ) = 0.1719 = 17.2 % (for sample 2 fresh yam)

where  $\lambda$  is the latent heat of vaporization of water at the inlet temperature of the product (Chapuis *et al.* 2017).  $\lambda$  is 2413 kJ/kg °K (standard value at ambient temperature). The remaining parameters in the equation had earlier been defined in Equation 6. Relating the values obtained for the energy efficiency of the samples (i.e. dry and fresh yam samples) whose values were lower compared to what was recorded by Kudra (2009). The values obtained could be as a result of the type of oil that was used to power the dryer which have a lower calorific value due to its nature (spent oil) as compared to when other fuel type such as diesel, petrol, kerosene which have high calorific values is used. The spent oil used tends to reduce the drying temperature of some of the samples due to its lower calorific value especially the fresh yam sample with high moisture content.

### 3.1.8 Thermal efficiency of the dryer, $\eta_T$

**Thermal efficiency, ( $\eta_T$ )** was defined according to Strumillo *et al.* (2014) based on the inlet air temperature ( $T_{in}$ ), the outlet air temperature ( $T_{out}$ ) and the ambient temperature ( $T_{amb}$ ), as shown in Equation 7 and obtained as 53.2%.

where, inlet air temperature,  $T_{in} = 105^\circ\text{C}$ , Outlet air temperature,  $T_{out} = 65.8^\circ\text{C}$  and Ambient air temperature,  $T_{amb} = 31.3^\circ\text{C}$

### 3.1.9 Heat losses to the ambient, $Q_{amb}$

Heat losses to the ambient,  $Q_{amb}$  was evaluated from Equation 8 and obtained as follows:

The value for  $C_p$  was determined according to the empirical correlations suggested by Choi and Okos (1986) which proposes that the thermal property of a food material is equal to the sum of the thermal properties of all the components of the food material (This is very relevant for cassava).

Meanwhile, the specific heat capacity of yam according to Irene and Avi (1998) ranged between 1.636 kJ/kg °C to 3.26 kJ/kg °C at different moisture contents. Therefore, Enthalpy of wet and dry products ( $h_{wp}$  and  $h_{dp}$ ) was obtained as 102.038 kJ/kg and 107.254 kJ/kg respectively.

where  $T_{wp} = 31.3^\circ\text{C}$ ,  $T = 65.8^\circ\text{C}$

Hence, heat losses to the ambient are as presented in Table 2.

The heat losses of the flash dryer used was high compared to what was recorded by Rotstein and Crapiste (1997). This may be due to the fact that the flash dryer used was not insulated, which tends to increase the level of heat losses in and across the drying duct of the dryer.

**Table 2. Amount of heat losses from the dryer to the ambient**

Product samples	Amount of Heat losses ( $Q_{amb}$ ) to the ambient (MJ/h)
G <sub>1</sub> (Dry yam)	88868.989 kJ/h = 88.9 MJ/h
G <sub>2</sub> (Dry yam)	88872.5364 kJ/h = 88.9 MJ/h
G <sub>1</sub> (Fresh yam)	88944.2564 kJ/h = 88.9 MJ/h
G <sub>2</sub> (Fresh yam)	88982.95912 kJ/h = 89 MJ/h

## 3.2 Physico-chemical Properties of Instant Pounded Yam Flour prepared from Fresh and Old Yam

The physico-chemical properties of the yam flour are indication of the quality of the final product as affected by the performance of the flash dryer are as presented in Table 3 and Appendix 1 to 10

### 3.2.1 Crude protein, Crude fibre, Ether extract, Ash, Dry matter and Carbohydrate

The physico-chemical properties of the IPYF produced from fresh and dry yam are as shown in Table 3 while the analysis of variance is as represented in Appendix 1 to 10.

**Table 3: Physico-chemical properties of Instant Pounded Yam flour**



Sample	Moisture content (%)	Particle size ( $\mu\text{m}$ )	Crude protein (%)	Ash (%)	Ether extract (%)	Crude fibre (%)	Dry matter (%)	CHO (%)
Fresh yam(G <sub>1</sub> )	83.7	4.5	2.14	3.2	0.4	2.3	92.2	91.96
Fresh yam(G <sub>2</sub> )	83.7	3.5	2.1	3.8	0.37	2.2	91.85	91.43
Dry Yam (G <sub>1</sub> )	52.63	4.5	2.45	2.7	0.55	2.6	93.09	91.7
Dry Yam (G <sub>2</sub> )	52.63	3.5	2.38	2.3	0.52	2.5	93.17	92.3
Fresh yam(G <sub>1</sub> )	83.7	4.5	2.14	3.2	0.4	2.3	92.2	91.96
Fresh yam(G <sub>2</sub> )	83.7	3.5	2.1	3.8	0.37	2.2	91.85	91.43
Dry Yam (G <sub>1</sub> )	52.63	4.5	2.45	2.7	0.55	2.6	93.09	91.7
Dry Yam (G <sub>2</sub> )	52.63	3.5	2.38	2.3	0.52	2.5	93.17	92.3

The analysis of variance showed a significant effect of the physico-chemical properties on the types of yam used. The result obtained for crude protein (as in Table 3) shows that there was significant ( $P \leq 0.05$ ) difference in the samples, with the dry yam sample (grater 1 (with particle size of  $4.5 \mu\text{m}$ )) having the highest crude protein (2.45%) while fresh yam (grater 2 (with particle size of  $3.5 \mu\text{m}$ )) has the least value (2.10%). These signifies that dry yam sample with larger particle size is much better in protein content than the other sample. Meanwhile, protein is one of the most essential nutrients needed as it is the source of amino acids needed for proper body maintenance and growth. Also, proteins are structural components of tissues, blood, enzymes, hormones and immunoglobulins (Afolabi *et al.* 2012).

The highest and least values of ash are 3.80% and 2.30 for fresh (G<sub>1</sub>) and dry (G<sub>2</sub>) yam samples respectively. The higher ash content could signifies that fresh yam sample will have higher mineral content than the dry yam due to its freshness which have not undergone any storage method unlike the dry yam that had been dried (stored) for a period of time before being used in the production of IPYF flour. The highest and least values for ether extract were 0.55% (for dry yam-G<sub>1</sub>) and 0.37% (for fresh yam-G<sub>1</sub>) which shows a significant difference at  $P \leq 0.05$ . Ether extract also known as crude fat is the oil content in a feed and also the traditional measure of fat in food products (Anon, 2018).

The high ether extract in dry yam is an indication of the level of its fat content which is more than that of the fresh yam sample. For crude fibre content, the values ranged between 2.60% to 2.50% for dry yam (G<sub>1</sub> and G<sub>2</sub>)

and 2.20% to 2.30% for fresh yam ( $G_1$  and  $G_2$ ) respectively. Crude fibre is a measure of the quantity of indigestion of some food components such as cellulose, pentosan, lignin present in foods. Due to this fact, the high content of crude fibre in dry yam may be an indication that fresh yam sample with lower value of crude fibre content will digest more easily (faster) than the dry yam sample. 93.17% was recorded as the highest value of dry matter content for dry yam ( $G_2$ ) and 91.85% for fresh yam ( $G_1$ ) as the least value. These means both samples have less than 10% ( $< 10\%$ ) moisture which is the standard for safe storage of product (i.e both samples are within the limit of storable moisture content that microorganism cannot survive (Anon, 2016a)).

Also, 92.30% and 91.43% were recorded as the highest and least values of carbohydrate for samples  $G_2$  and  $G_1$  (dry and fresh samples) respectively. This is within the required range of daily carbohydrate content necessary for healthy growth. Although, excessive consumption and unhealthy intake of carbohydrate food such as crackers, cakes, flour, jams, sugar or corn syrup can cause obesity, type II diabetes and cancer. However, since starch remain the main form of carbohydrate, and that yam tubers basically, are composed of about 70% starch content in its nutritional values. This invariably means, the samples were good source of energy as required in the nutritional requirements and that their intake is not an unhealthy eating habit as they are not refined carbohydrate (Anon, 2018).

### 3.2.2 Physical properties of Instant Pounded Yam Flour

Table 4 shows the physical properties of the IPYF produced while the ANOVA data were as shown in the Appendix.

**Table 4. Physical properties of Instant Pounded Yam flour**

Sample	Moisture content (%)	Particle size ( $\mu\text{m}$ )	Amylose (%)	Viscosity (%)	Paste clarity ( $^{\circ}\text{C}$ )	Pasting temp ( $^{\circ}\text{C}$ )	Solubility(%)	Amylopectin (%)
Dry yam( $G_1$ )	83.7	4.5	17.69	26.80	71.20	67.50	46.85	36.79
Dry yam( $G_2$ )	83.7	3.5	17.62	26.30	70.80	67.20	46.79	36.74
Fresh Yam ( $G_1$ )	52.63	4.5	15.97	23.50	68.40	71.80	42.68	31.88
Fresh Yam ( $G_2$ )	52.63	3.5	15.88	23.10	68.10	71.50	42.59	31.83
Dry yam( $G_1$ )	83.7	4.5	17.67	26.70	71.00	67.35	46.65	36.77
Dry yam( $G_2$ )	83.7	3.5	17.59	26.27	70.80	67.20	46.59	36.83
Fresh Yam ( $G_1$ )	52.63	4.5	15.95	23.50	68.20	71.60	42.48	31.64
Fresh Yam ( $G_2$ )	52.63	3.5	15.86	23.10	67.90	71.37	42.39	31.67
Standard deviation			0.89	1.62	1.41	2.13	2.10	2.51



### **Amylose, Amylopectin and Viscosity**

The physical properties as shown in Table 4 shows that, dry yam sample has high value of amylose / amylopectin with value of 17.69%, 36.79% while fresh yam sample has the lowest value with 15.86% and 31.88% respectively. These correlates with the study of Adegunwa *et al.* (2011) which stated that high values of amylose / amylopectin is an indication of type –A starch which has the property of high digestibility. The high digestibility of some of these starchy products may be of importance in food preparations especially for infant or old people who require more readily digestible foods. Meanwhile, samples with lower values of amylose / amylopectin may be an indication of low digestibility which could be used in the prevention of obesity, diabetes and other related diseases when used as food ingredients (Hung and Morita, 2005). The viscosity of a material depends on the shape and swelling power of the granule and amylopectin granules interaction (Ring *et al.* 1987).

It also indicates the water binding capacity of the starch and it occurs at the equilibrium point between swelling causing an increase in viscosity rupture and alignment causing its decrease. Thus, the final viscosity indicates the ability of the material to form a viscous paste after cooking and cooling (Adegunwa *et al.* 2011). From the study, the dry yam samples with high viscosity value, 26.80% may have a viscous paste after cooking than the fresh yam samples with lower value of viscosity. This may be due to the fact that dry yam has been stored for a period of time which have made its moisture to shrink (lost) unlike the fresh yam which moisture is still in its fresh form.

### **Paste clarity and Pasting temperature**

The pasting temperature for fresh yam sample is 71.8°C higher than that dry yam of 67.5°C. This shows a significant level at  $P \leq 0.05$ . Pasting properties is an indication of gelatinization time during processing especially when it is on the high side. It is the temperature related to water binding capacity. An increase in pasting temperature signifies higher water binding capacity property of starch due to degree of association between starch granules (Adegunwa *et al.* 2011). In view of this, the high value of pasting temperature (71.8°C) in fresh yam sample may be an indication of good gelatinization (i.e. water binding capacity) over dry yam sample of lower value of pasting temperature (i.e. 67.5°C). Standard deviation (S. D.) was obtained from Equation 10 as shown in Table 4. The value obtained for S.D. for all the physical properties were low, which is an indication that the value is within the range of the expected value as stated by Anon (2018b).

### **Dispersibility**

The dispersibility of a mixture in water indicates its ability to reconstitute which invariably means the higher the dispersibility of a mixture, the better is its reconstitution property. Thus, the result of this study shows that the dry yam sample with high value of dispersibility (86.44%) will reconstitute better than the fresh yam with lower value of 81.63%. This may be due to the fact that the dry yam has been stored for a period of time before being used for the production of yam flour which has made its moisture to shrink unlike the freshly harvested tubers whose moisture is still very fresh.

## **3.2.3 Functional Properties**

### **Loose and Packed bulk densities**

The functional properties of the sample is as shown in Table 5, while the ANOVA Tables is as shown in Appendix 7 and 8



**Table 5. Functional property parameters of Instant Pounded Yam Flour**

Sample	Loose bulk density (g/ml)	Packed bulk density (g/ml)	WAC(g/100g)	OAC(g/100g)	SP(g/g)
Fresh yam(G <sub>1</sub> )	0.4239	0.5407	165	83	15.10
Fresh yam(G <sub>2</sub> )	0.4236	0.5411	162	86	15.3
Dry yam(G <sub>1</sub> )	0.4128	0.5269	176	95	18.6
Dry yam(G <sub>2</sub> )	0.4125	0.5273	173	92	18.4
Fresh yam(G <sub>1</sub> )	0.4239	0.5407	165	83	15.10
Fresh yam(G <sub>2</sub> )	0.4236	0.5411	162	86	15.3
Dry yam(G <sub>1</sub> )	0.4128	0.5269	176	95	18.6
Dry yam(G <sub>2</sub> )	0.4125	0.5273	173	92	18.4

The result shows that the loose bulk density of the yam flour samples varied from 0.4239g/ml to 0.4128 g/ml for fresh and dry yam respectively. The packed bulk density also ranged between 0.5411 g/ml to 0.5273 g/ml for fresh and dry yam samples respectively. The difference observed in bulk density value is found to be insignificant. Bulk density gives an indication of the relative volume of packaging materials required which is suitable for greater ease of dispersibility and paste thickness reduction especially, if it is on the increase size. Whereas, low bulk density flours are good physical qualities to determine transportation and storability due to easy handling. This result therefore showed that the flour with high bulk density should be used where such properties are required.

The statistical analysis shows that these differences were significantly difference at  $P \leq 0.01$ . Meanwhile, the packed bulk density of approximately 0.53g/ml for fresh yam is the same with that reported by Igyor *et al.* (2004), whereas, the loose bulk density of 0.4125 g/ml for dry yam differed from 0.60 g/ml reported by the same author. Also recorded by Igyor (2004) was the packed bulk density of 0.62 g/ml for white yam flour which is different from the experimental value of 0.541 g/ml and the loose bulk density of 0.412 g/ml contrary to 0.74 g/ml that was reported by Igyor (2004). The observed variations in the results could be assigned to the differences in the state or form in which the tubers were used (fresh and dry yam tubers). Also, factors such as age, variety, growth season and cultivar's type of root tubers can also influence the physico-chemical properties (Niba *et al.* 2001).

#### **Water and Oil absorption Capacities (WAC) and (OAC)**

The water absorption capacity (WAC) and oil absorption capacity (OAC) is as shown in Table 5. The WAC ranged from 1.65 g/ml to 1.62 g/ml for fresh yam sample and 1.76 g/ml to 1.73 g/ml for dry yam sample. The value is in line with the report of Amandikwa (2012). The low values of the sample may be as a result of the high moisture content of the fresh yam which tends to reduce the drying temperature during the drying process. WAC is very important that it serves as an indication of how flour can be incorporated into aqueous food formulations especially those involving dough handling. Niba *et al.* (2001) stated that WAC is a very vital property that the product is required to produce especially in baking application. On the other hand, OAC for fresh yam and dry yam respectively ranged between 0.86 g / ml to 0.95 g / ml which is lower than 1.66 g/ml reported by (Niba *et al.*2001). High OAC gives a valuable in ground meat formulation, meat replacers and extenders (Niba *et al.*2001). Oil also gives soft texture and good flavor to food. Hence, oil absorption in food improves mouth feel and flavour retention. From this statement, it can be inferred that dry yam sample may be better than fresh yam in terms of texture, flavor and taste which are the three main factors for mouth acceptability.

### Swelling Power (SP)

Sample G<sub>1</sub> (dry yam) has high value of swelling property with value, 18.6 g/ml and G<sub>1</sub> fresh yam has the lowest value of 15.10 g/ml. It has been stated by Adegunwa *et al.* (2011) that the main factors affecting the pasting properties of flour and starch are the swelling power and amylose content. These properties could also influence some of the pasting properties of starch, since the pasting process involves granular swelling, leaching out of amylose and disruption of granules during heating (Adegunwa *et al.* 2011). From this statement, this shows that dry yam of high swelling property could be an influence in the pasting properties of starch.

### 3.2.4 The effects of moisture and particle size parameters of the Instant pounded yam flour produced

Table 6 shows the duration of drying as related to particle size and drying temperature of the sample

**Table 6. Drying Temperature Vs Particle size characteristics before, during and after drying for IPYF samples**

Sample size	Weight before grating (kg)	Feed rate (kg/hr)	Drying temperature (°C)	Drying time (min)	Weight after drying (kg)	Moisture content (%)
(G <sub>1D</sub> ) 4.5 μm	7.48	49.87	150	9	3.9	19.8
(G <sub>2D</sub> ) 3.5 μm	11.48	52.90	150	13	3.4	19.3
(G <sub>1F</sub> ) 4.5 μm	5.70	17.12	170	20	3.0	12.7
(G <sub>2F</sub> ) 3.5 μm	10.10	18.95	170	32	1.4	13.6

where:

- G<sub>1D</sub> represents Grater 1 (i.e. 4.5 μm) for dry yam sample
- G<sub>2D</sub> represents Grater 2 (i.e. 3.5 μm) for dry yam sample
- G<sub>1F</sub> represents Grater 1 (i.e. 4.5 μm) for fresh yam sample
- G<sub>2F</sub> represents Grater 2 (i.e. 3.5 μm) for fresh yam sample

Table 6 shows that, the drying temperature and time for the dry yam samples (i.e G<sub>1</sub> and G<sub>2</sub>) is lesser than that of fresh yam samples. This may be due to their variation in moisture content, as the fresh yam have much moisture than the stored yam which makes its drying time to be prolonged. Meanwhile the moisture content of the fresh yam sample was lower than that of the dry yam; this may be due to the continuous back-mixing of the fresh yam sample during drying which was done to aid the drying operation. The process models developed for the food nutrition quality parameters for each of the dependent variables is as shown in Appendix C. Analysis of Variance (ANOVA) was used to test for the existence and sufficiency of the process models as shown in the detail analysis of Tables B1- B10 in the Appendix. The high value of regression coefficients (R<sup>2</sup>) obtained from the analyses signifies the degree or level at which the variations in the response variables (i.e. the moisture content and the product particle sizes) were being clarified by the set of independent variables (i.e. the nutritional composition of the IPYF produced (such as crude protein, ash, fibre, CHO, among others)).

However, high values of the Regression Sum of Squares (RSS) as compared to the low values of residual sum of squares (ESS) and low value of standard error indicates that the models have accounted for greater amount

of the variations in the independent (response) variables. The models are thus significant at 95% confidence level. This invariably means that the model variables are appropriate for the data (Iya, 2005; Olaniyan, 2006).

### 3.2.5 Flour yield of Instant pounded yam flour produced

This was obtained as 29.12 % and 16.49 % for dry and fresh yam samples respectively from equation (12). The value shows that, the flour yield of dry yam (29.12%) is higher than that of fresh yam sample with 16.49% of the total raw sample of 28.5kg. This invariably means that, for food processors whose interest is profitability especially in terms of yield, dry yam tubers will be preferred in the production of instant pounded yam flour as compared to fresh yam tubers.

### 3.2.6. Assessment of Yam Processing Methods (Colour)

Table 4.7. shows the physical characteristics of the IPYF sample produced as related to its colour

**Table 7. Colour characteristics of the pounded yam flour produced**

Sample	Moisture Content	Particle Size	% L	a(Yellowishness)%	b(Blueish)%	% Dispersibility
Fresh yam(G <sub>1</sub> )	83.7	4.5	61.20	14.80	2.30	81.74
Fresh yam(G <sub>2</sub> )	83.7	3.5	60.80	14.30	1.80	81.68
Fresh Yam (G <sub>1</sub> )	52.63	4.5	56.30	56.30	3.40	81.71
Fresh Yam (G <sub>2</sub> )	52.63	3.5	56.10	56.10	2.70	81.63
Dry yam(G <sub>1</sub> )	83.7	4.5	61.20	14.80	2.30	86.39
Dry yam(G <sub>2</sub> )	83.7	3.5	60.80	14.30	1.80	86.44
Dry Yam (G <sub>1</sub> )	52.63	4.5	56.30	56.30	3.40	81.67
Dry Yam (G <sub>2</sub> )	52.63	3.5	56.10	56.10	2.70	86.68

### Assessment of Colour

The result of the Hunter's L\*a\*b colour analysis of the samples to show the level of the lightness of the flour is as shown in the Appendix. The study established that, despite the high drying temperature that the samples were subjected to, the creamy colour of the sample is still retained, which is an indication in the use of a flash dryer that the composition (i.e the characteristic feature of the sample) is maximally maintained. However, unlike the other IPYF in the market that was treated with sodium meta-bisulphite which is whitish in colour. This means for a more whiter colour, there is need to treat this sample according to the procedure of Nanam *et al.* (2005) which stated that; The sample of yam to be processed into IPYF should be pre-heated with sodium meta-bisulphite before drying in order to maintain the whitish colour (an appealing colour) of yam flour.

The method was to wash the whole tubers with the peel to remove dirt, then peel, wash the peeled yam, thinly slice the yam (to say, 1-2cm thickness), dip in 0.5% sodium meta-bisulphite for about 3 minutes, then rinse in clean water, parboil for a specified period of time, cool, grate using 4.5µm grater size and dry in a flash dryer.

## 4. CONCLUSIONS AND RECOMMENDATIONS

### 4.1 Conclusions

The study established that for optimal usage in the use of a flash dryer especially when spent oil is used in proportion with other types of oil as in the case of the flash dryer that was used, the proportion in its usage should be lower to other type of oil in other to boost the calorific value of the fuel. Also, moisture content of yam tuber and its particle size (in mashed form) should not be underestimated as they contribute significantly to the energy efficiency of the dryer. Small particle size product (have more moisture than the larger particle size, hence took longer time to dry compared to the larger particle size) tends to cause hindrance and thus prevent free flow of product when loading into the drying chamber. Additionally, to overcome heat losses in the dryer, the dryer should be well insulated in other to conserve more energy within the dryer.

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## APPENDICES

Table B-1. ANOVA of multiple regression of Crude protein as a function of moisture and particle size parameters

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### ANOVA

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Source	SS	SS%	MS	F	F Signif	df
Regression	0.180	100	0.09005	1000.6	3.10126E-07	2
Residual	0.000450	0	9E-05			5
Total	0.181	100				7

**Table B-2 ANOVA of multiple regression of Ash as a function of moisture and particle size parameters**

<b>ANOVA</b>						
Source	SS	SS%	MS	F	F Signif	Df
Regression	2.020	80	1.010	10.10	0.01754	2
Residual	0.500	20	0.100			5
Total	2.520	100				7

**Table B-3 ANOVA of multiple regression of Dry matter as a function of moisture and particle size parameters**

<b>ANOVA</b>						
Source	SS	SS%	MS	F	F Signif	df
Regression	2.479	96	1.239	67.02	0.000245	2
Residual	0.09245	4	0.01849			5
Total	2.571	100				7

**Table B-4 ANOVA of multiple regression of CHO as a function of moisture and particle size parameters**

<b>ANOVA</b>						
Source	SS	SS%	MS	F	F Signif	df
Regression	2.479	96	1.239	67.02	0.000245	2
Residual	0.09245	4	0.01849			5
Total	2.571	100				7

**Table B-5. ANOVA of multiple regression of Amylose as a function of moisture and particle size parameters**

<b>ANOVA</b>						
Source	SS	SS%	MS	F	F Signif	df
Regression	5.999	100	2.999	74982.5	6.41821E-12	2
Residual	0.000200	0	4E-05			5
Total	5.999	100				7

**Table B-6 ANOVA of multiple regression of Viscosity as a function of moisture and particle size parameters**

<b>ANOVA</b>						
Source	SS	SS%	MS	F	F Signif	df



Regression	21.53	100	10.77	10765.0	8.21415E-10	2
Residual	0.00500	0	0.00100			5
Total	21.54	100				7

**Table B-7 ANOVA of multiple regression of Paste clarity as a function of moisture and particle size parameters**

<b>ANOVA</b>						
<i>Source</i>	<i>SS</i>	<i>SS%</i>	<i>MS</i>	<i>F</i>	<i>F Signif</i>	<i>df</i>
Regression	15.37	100	7.685	7685.0	1.90716E-09	2
Residual	0.00500	0	0.001000			5
Total	15.38	100				7

**Table B-8 ANOVA of multiple regression of Solubility as a function of moisture and particle size parameters**

<b>ANOVA</b>						
<i>Source</i>	<i>SS</i>	<i>SS%</i>	<i>MS</i>	<i>F</i>	<i>F Signif</i>	<i>df</i>
Regression	35.04	100	17.52	194665	5.91039E-13	2
Residual	0.000450	0	9E-05			5
Total	35.04	100				7

**Table B-9 ANOVA of multiple regression of oil absorption capacity as a function of moisture and particle size parameters**

<b>ANOVA</b>						
<i>Source</i>	<i>SS</i>	<i>SS%</i>	<i>MS</i>	<i>F</i>	<i>F Signif</i>	<i>df</i>
Regression	162.00	90	81.00	22.50	0.00316	2
Residual	18.00	10	3.600			5
Total	180.00	100				7

**Table B-10. ANOVA of multiple regression of water absorption capacity as a function of moisture and particle size parameters**

<b>ANOVA</b>						
<i>Source</i>	<i>SS</i>	<i>SS%</i>	<i>MS</i>	<i>F</i>	<i>F Signif</i>	<i>Df</i>
Regression	21.78	100	10.89	680.62	8.10214E-07	2
Residual	0.08000	0	0.01600			5
Total	21.86	100				7