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# Development and performance evaluation of a cabinet drying machine for the production of yam flour

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**Abstract**
The Cabinet Drying Machine comprising electrical unit, heating unit and drying unit was designed, developed and its performance successfully evaluated. The machine was developed using locally sourced materials to reduce drudgery in the drying of per-boiled yam, overheating and other burnt defects as well as contaminations and enhance production of adequate quantity and quality of processed yam flour. Performance test analysis that was carried out, revealed average drying rate (throughput) and drying efficiency for cabinet machine are 21.90g/hr and 87.35% respectively while. Thus, the cabinet drying machine is capable of drying and preserving perishable commodity with good control of the heating and of the preserving conditions for both medium and large-scale production.

**Keywords:** development, performance evaluation, cabinet drying machine, production, yam flour

## Introduction

Agriculture is seen as a driver of growth and development in Nigeria and many other emerging countries. Nigeria produces more than 70–76% of the world's yams, making it by far the greatest producer in the world (Okorie & Lin, 2022) [13]. Yams are a reliable food crop that not only contribute to food security but also provide employment opportunities and money in Nigeria's yam-producing regions. Yam tubers have a high-water content and have received additional water during parboiling (for atomizing the water content). Unlike other foodstuffs, this one requires a high temperature drier for proper drying as well as venting controls that make it simple to change the drying temperature (Amankwah, Sarpong & Kyere, 2022) [6]. Dioscorea species, which are used to make yam, are harvested every year between June and December. It is a crop of tubers with over 600 species, and due to its high moisture content, it is particularly perishable while it is fresh (Matsumoto, Asfaw, De-Koeyer, Muranaka, Yoshihashi, Ishikawa, Adebola & Asiedu, 2021) [12]. Because conventional preservation techniques lack temperature control and have negative impacts on the standard of the dried product, challenges with preservation are unavoidable. It is almost impossible to overstate the necessity for alternate drying techniques that preserve preservable temperature, avoid agglomeration, and provide excellent end products.

The capacity to preserve food is directly related to the level of technological development. The slow progress in upgrading traditional food processing and preservation methods in West Africa contributes to food and nutritional insecurity in the sub-region. Modern methods of food processing such as extrusion cooking, explosion puffing and instantiation appear to make the starch in food readily digestible (Ayodeji, 2012) [9]. Yam is a tuber crop rich in carbohydrate, vitamins and mineral salts, besides; it has several components that serve as raw materials for medicine. The yam tubers when harvested, posses about 70% of moisture. Nigeria is the largest producer of yam in the West Africa. Flour which is a product of yam is becoming one of Nigerians source of foreign earnings. The starchy content of yam allows it to form a bond when beaten in a mortar which can then be consumed as meal (Ayodeji, 2017) [8].

Pounded Yam is a staple food, which is consumed by almost every tribe in Nigeria. The indigenous process of production is very laborious; it requires physical pounding by two or more men or women depending on the quantity, in mortars with pestles. Instant Pounded Yam flour (IPYF) brings succour to pounded yam lovers as the drudgery of pounding is eliminated. It also makes people desire it the more as preparing it is easier now as compared to the traditional method of pounding. Regrettably, the larger percentage of the yearly turnover in yam harvest are not been fully utilized which has informed the need for the development of custom made dryer as integrated into the *poundo* yam flour process plant (Ayodeji, 2012) [9] to process yam into instant *poundo* yam flour to be consumed by people when there is scarcity. In order to achieve the aim of this research, the following questions were answered; the location and orientation of the dryer in the process plant to permit continuous flow of material, the physical and chemical properties of the yam flowing through the process plant at the location of the dryer, the efficiency of the dryer and the quality of the yam chips produced from the developed dryer.

Pounded yam flour (*poundo* yam), a faster and easier means of preparing pounded yam has become popular and acceptable contributing more than 200 dietary calories per capital daily for over 150 million people in West Africa and serves as an important source of income. It is produced from yam, *Dioscorea* (spp.) one of the oldest known recipes to man consumed mostly by people of sub-Sahara region as source of carbohydrate. However, its production process from yam is energy consuming, hence the need for an efficient process for its mass production. Drying, the major process in the plant is the focus of this work to develop and evaluate the performance of an effective drier and its suitability for applications in food industry. Therefore the objectives of this study are to design and fabricate a Cabinet Drying Machine for the production of yam flour and conduct performance evaluation of the machine.

**Methods**

The machine was designed to dry per-boiled yam in a manner to remove the moisture in the per-boiled for it to be milled or pulverized and enhance the production of adequate quantity and quality of pounded yam during further processing. The use of a mirror-face stainless steel plate in fabrication of the machine because of its high reflection and retention of heat as well as low speed fan for gradual and moderate circulation of heat.

**1. Selection of fan**

The fan rating is determined as 2watts. The fan aids in heat distribution by blowing (heated air) heat generated from the heating chamber into the drying chamber

**2. Determination of drying volume**

The drying chamber is determined as $0.0625mm^3$. The drying chamber is rectangular with mesh of 10mm and separated by a distance of 2mm.

The volume of the drying chamber is obtained from the equation given below

$$V = L \times W \times H \quad (2)$$

Where, v is volume,

L is length
W is width
H is height

**3. Determination of moisture content**

The moisture content was determined as 12.64% by the gravimetric method according to the official methods of analysis employed by Association of Official Analytical Chemist (AOAC) 2009 given as.

$$M_c = \frac{M_i - M_f}{M_i} \times 100 \quad (3)$$

Where,
$M_c$ = moisture content
$M_i$ = mass of per-boiled yam before drying
$M_f$ = mass of per-boiled yam after drying

**4. Determination of amount of water removed**

The amount of moisture removed was determined as 14.67kg from the relation given below.

$$M_r = M_o \frac{M_i - M_f}{100 - M_f} \quad (4)$$

Where,
$M_r$ = amount of moisture removed
$M_o$ = initial mass of the plastic pellets to be dried
$M_i$ = initial moisture content, % wet basis
$M_f$ = final moisture content, % wet basis

**5. Determination of drying rate, $T_d$**

The drying rate is determined as 21.90g/hr from the relation given below,

$$D_r = \frac{M_w}{T_d} \quad (5)$$

Where,
$D_r$ = drying rate
$M_w$ = moisture to be removed
$T_d$ = drying time

**6. Determination of drying weight ($M_d$)**

The drying weight of a particular product depend largely on its moisture content and is expressed as the ratio of the difference between wet ($W_w$) and dried ($W_d$) weight of the product to its drying weight. Therefore, propose the drying weight as the weight of the material outside the drying chamber. This is determined from the expression

$$M_d = 0.503P^{0.037} + F_o^{0.127} \quad (6)$$

Where P is the drying pressure
$F_o$ is Fourier number

However, the drying chamber is calculated using the model expressed as

$$P = \frac{V_\alpha t}{A} \text{ x } W \quad (7)$$

Where $V_a$ is drying chamber air flow velocity
A is drying chamber area
T is drying time
W is width of the drying chamber

**7. Determination of shrinkage effect**

Different drying methods have different effect on the quality of a product, thus this effect may be on the volume shape and/or entire composition. Hence the changes in a product that causes the deformation of both physical and chemical compositions.

$$K = \frac{V_p}{W_a 3} \quad (8)$$

Given,

$$W_a = \frac{A_p}{L} \quad (9)$$

Where $V_p$ is volume of moisture in the material
$A_p$ is projected area of the drying chamber

**8. Determination of the heating power of the heating element**

The heating power of the heating element is determined as 2kw from the relation given below

$$Q = mC_p\theta = IVT \quad (10)$$

But P =IV

$$Q = PT \quad (11)$$

Hence P = Q/T

Where, P = power of heating element/heater band
Q = quantity of heat
m = mass of materials
$C_p$ = specific heat capacity of the plastic
θ = temperature rise
I = steady state current
V = potential difference between the terminals of the heating coils in volts

**9. Determination of the heat source/quantity of heat needed for drying**

The drying temperature of most varieties of yam is between $50^0$C – $80^0$C. We choose $100^0$ C target temperature of the heating chamber. The materials must be raised from room temperature $25^0$ C to $100^0$C. Assuming a yam chunk of mass 500g as per-boiled yam, so the quantity of heat needed to raise this temperature from $25^0$C to $100^0$C can be calculated thus:

Q = heat needed to raise the material to its drying point

$$Q = mC_p\theta \quad (12)$$

Where, m = mass of material and measured at 25kg
$C_p$ = specific heat capacity of material and has been determined from standard table as 2.004KJ/KgK

θ = temperature change = 100 - 25 = $75^0$C.

The heat source must be able to generate this amount of heat and the amount of heat that will be lost through the walls of the heating chamber.

**Developmental procedure/description of the cabinet drying machine for the production of yam flour**

The major components of the developed cabinet drying machine (Figure 1) include heating element, thermocouple, temperature controller, low speed fan, drying mesh and drying chamber. The detailed production drawings for this machine fabrication are contained in the Appendix

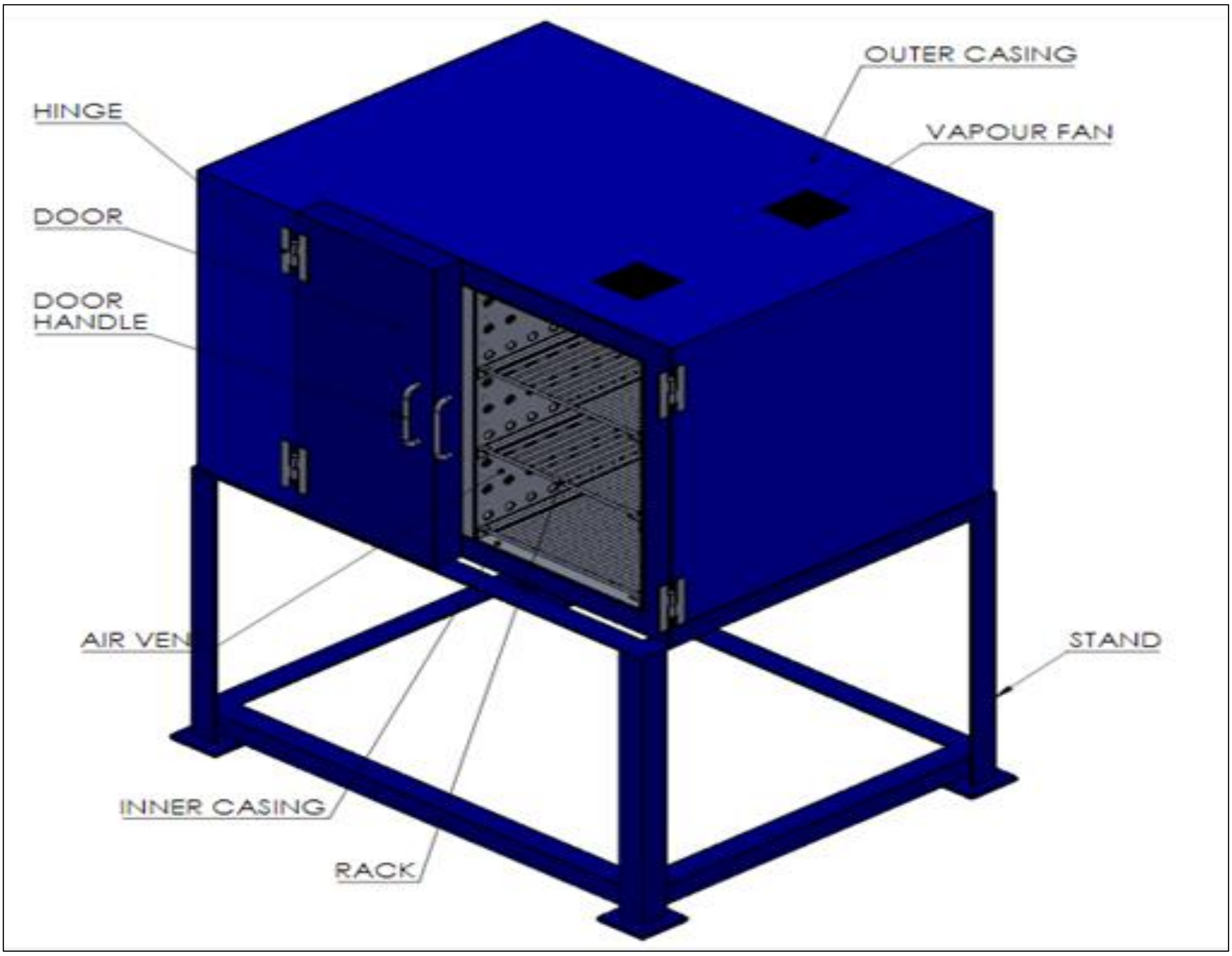


**Fig 1:** The Isometric view of the developed Cabinet Drying Machine

These components were assembled on a folded fiber insulated 2mm gauge stainless steel plate to ensure heat retention or avoid heat loss by means of heat transfer. The heating elements are connected to the electric mains which receive electric current and converts electrical energy to heat energy. The heating element is heated to preset temperature with the heat emitted from the heating element blown into the drying chamber by the electric fan. The fan blows in hot air inside the chamber through heat convection process until a certain time frame for drying to occur is reached.

The cabinet dryer is powered by an electric main via a cable connected to the electrical components that energizes the equipment with a voltage of 220v and current of 15A. The design of the cabinet dryer included the determination of the area of the drying chamber, electrical unit powers, heating chamber and heating elements and also selection of a convenient material for the fabrication of the individual units. The bulk of the parts of the dryer were fabricated using stainless steel plates, this is because it is resistant to corrosion. It has high reflection and retention of heat necessitating its use by many industries for fabrication of edible and process unit equipment. It is readily available and durable compared to other materials.

**1. Performance testing procedure**

White yam harvested from the Enugu areas will be used for the evaluation of this machine. Evaluations of the machine will be carried out at a temperature of $100^0$c. The voltage flow of the circuit and heating power of the heating element was designed to be 220V and 2000W respectively. The voltage supply and current flow were given to be 240V and 15A respectively. The per-boiled yam will be weighed to determine the weight before loading into the machine. The weighed samples of per-boiled yam will be placed by opening the door into the drying chamber. The dried per-boiled yam will be weighed after drying to know the amount of moisture removed and the drying rate was calculated to obtain the drying efficiency, moisture content (wet and dry basis) input and output capacities, in accordance to association of official analytical chemist (AOAC, 2000). The performance evaluation will be carried out more times to obtain the average performance of the machine.

**2. Development of mathematical model procedures for performance evaluation of the machine**

The effects of voltage drop, temperature, current flow and heat transfer parameters on system responses: amount of moisture removed, drying efficiency and drying rate (throughput) were investigated. The temperature at the time of drying was recorded by a thermocouple embedded on the heating chamber. The objective was to understand the effect of heat transfer and drying system variables (quantity of heat, temperature and moisture content) on the performance of the machine.

From the table, the following independent factors or variables were considered; temperature, voltage supply, current flow, heating power, quantity of heat, torque etc. The dependent variables/responses of the machine were amount of moisture removed, moisture content (wet and dry basis), drying efficiency (DE), and drying rate (throughput).

**Amount of moisture removed $M_w$, (kg)**

The amount of moisture to be removed from a given quantity of per-boiled yam to bring the moisture content to a safe usable/processing level in a specified time is calculated from the equation below according Khurmi and Gupta 2009);

$$M_r = M_o \frac{M_i - M_f}{100 - M_f} \qquad (12)$$

Where,
$M_o$ = initial mass of the per-boiled yam to be dried
$M_i$ = initial moisture content, % wet basis
$M_f$ = final moisture content, % wet basis

**Moisture content ($M_c$)**

The moisture content was determined by the gravimetric method according to the official methods of analysis employed by Association of Official Analytical Chemist (AOAC, 2009).

$$M_c = \frac{M_i - M_f}{M_i} \text{ x } 100 \qquad (13)$$

Where,
$M_i$ = mass of per-boiled yam before drying
$M_f$ = mass of per-boiled yam after drying

**Moisture content of the wet basis**

$$\text{\% wet basis Mc} = \frac{Mi - Mf}{Mi} \; x \, \frac{100}{1} \qquad (14)$$

**Moisture content of the dry basis**

$$\text{\% dry basis Mc} = \frac{Mi - Mf}{Mf} \; x \, \frac{100}{1} \qquad (15)$$

**Average drying rate, $M_{dr}$ (kg/hr)**

Average drying rate, $M_{dr}$ will be determined from the mass of moisture to be removed by electric heat and drying time by the equation below:

$$M_{dr} = \frac{M_w}{T_d} \qquad (16)$$

Where,
$M_{dr}$ = drying rate
$M_w$ = moisture to be removed
$T_d$ = time taken for drying to occur

**Quantity of heat needed to evaporate water (KJ), Q**

$$Q = M_w \text{ x } h_{fg} \qquad (17)$$

Where,
$M_w$ = amount of moisture removed
$h_{fg}$ = the latent heat of evaporation of water (KJ/kg)
**Note:** amount of heat needed is a function of temperature and moisture content of the per-boiled yam chunk.

**Drying efficiency DE**

$$DE = \frac{wet\ basis}{dry\ basis} \times 100 \quad (18)$$

**Results and Discussion**

The cabinet drying machine performance test results shown in Tables 1 and 2 showed that its respective drying rate (throughput) and efficiency at a fixed quantity of 500.0g and drying temperature of $100^0$C is 21.90g/hr and 87.35% and its drying rate (throughput) and efficiency at variable quantity of 600g, 800g and 1000g is 41.53g/hr and 83.66% when electrically powered. And when powered with solar, its throughput and efficiency is 0.02525kg/hr and 2.37% respectively. Thus, the developed cabinet drying machine has a very good throughput, moisture removal strength and drying efficiency for mass production. It is also affordable and energy saving.

**Table 1:** Results of the performance test of the cabinet drying machine for the production of yam flour at fixed quantity of 500.0g and drying temperature of $100^0$C (Electrically powered).

| S/No | Weight of per-boiled yam before drying (g) | Weight of per-boiled yam after drying (g) | Time taken (mins) | % Moisture loss | Moisture loss (g) |
|---|---|---|---|---|---|
| 1 | 500.0 | 450.0 | 20 | 10.0 | 50.0 |
| 2 | 500.0 | 443.5. | 30 | 11.3 | 56.0 |
| 3 | 500.0 | 437.0 | 40 | 12.6 | 63.0 |
| 4 | 500.0 | 430.0 | 50 | 14.0 | 70.0 |
| 5 | 500.0 | 423.0 | 60 | 15.4 | 77.0 |
| Average | 500.0 | 436.8 | 40 | 12.64 | 63.2 |

From table 1 it shows that at fixed load and variable time (20, 30, 40, 50 and 60mins), the mass of dried yam decreased and the percentage moisture loss increased due to increase in drying time. From the Experimental, it was observed that optimum drying was achieved at 60mins of the drying chamber.

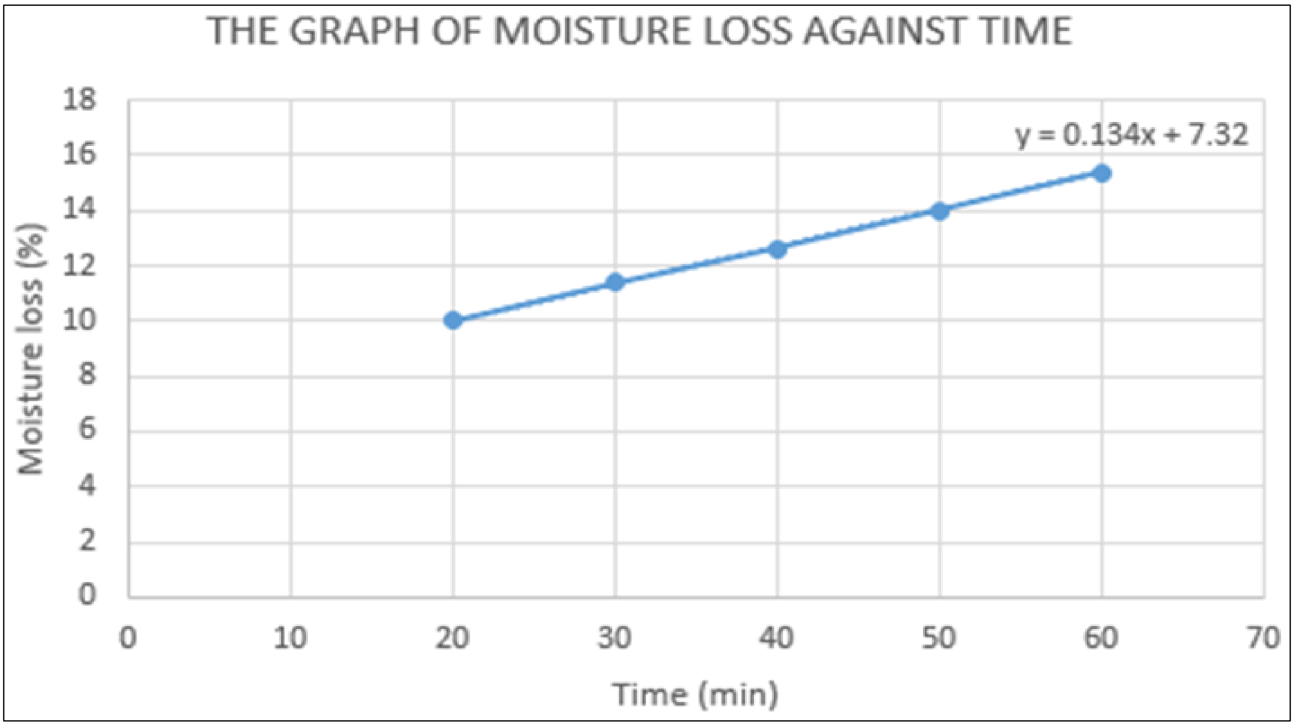


**Fig 2:** Interval plot of moisture loss versus time taken

Fig 2 shows various losses for different time intervals. The time taken at 20, 30, 40, 50 and 60mins respectively. This is an indication that moisture loss increases with an increment in time taken for drying to occur.

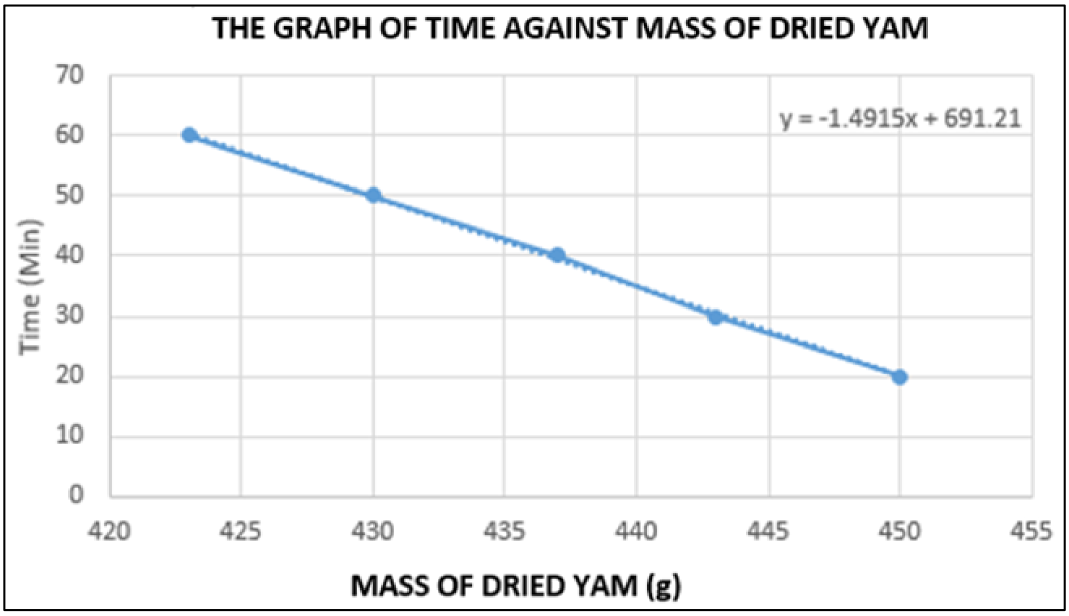


**Fig 3:** Interval plot of time versus mass of dried yam

Fig 3. Shows the various mass of dried yam for different time taken. The time taken at 20mins, 30mins, 40mins, 50mins and 60mins respectively. Time taken at 60mins has the highest moisture loss and least with time taken at 20mins. This shows that the time taken at 60mins has a good drying eff iciency while the time taken at 20mins of drying has the least.

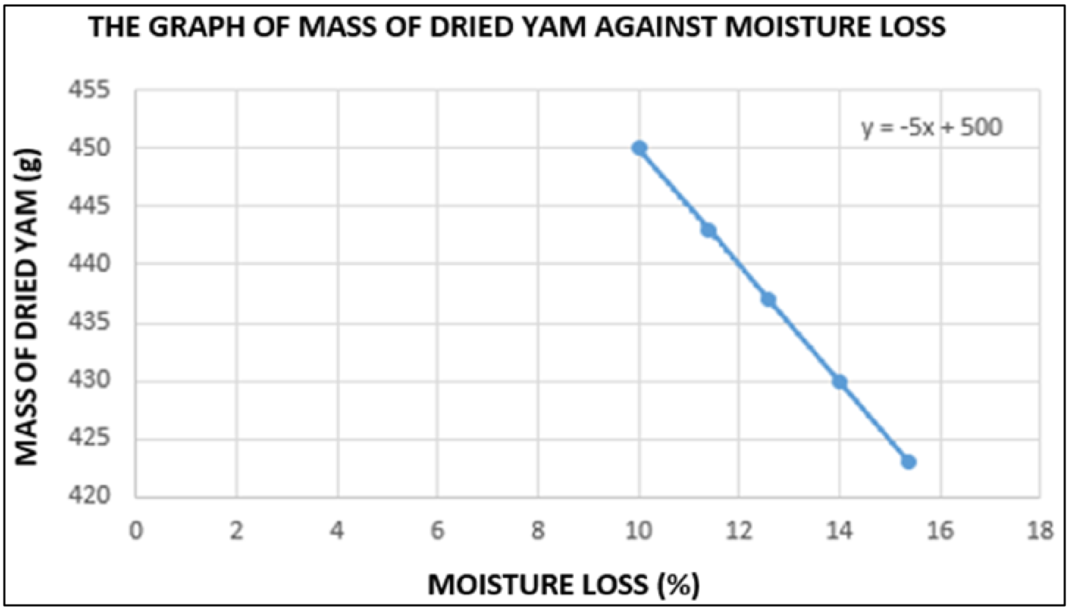


**Fig 4:** Interval plot of mass of dried yam versus moisture loss

Fig 4. shows the various moisture losses for different mass of dried yam at different time taken. This shows that moisture loss will affect the mass of dried yam with high moisture loss indicating greater efficiency of the dryer.

**Table 2:** Performance Test Results of development and performance evaluation of cabinet drying machine for the production of yam flour at a fixed time of 60mins.

| s/no | $M_i$ (g) | $M_f$ (g) | Time (mins) | % Moisture loss | Moisture loss |
|---|---|---|---|---|---|
| 1 | 200 | 134 | 60 | 33 | 66 |
| 2 | 400 | 317 | 60 | 21 | 83 |
| 3 | 600 | 500 | 60 | 17 | 100 |
| `4 | 800 | 687 | 60 | 14 | 113 |
| 5 | 1000 | 875 | 60 | 13 | 125 |

Table 2. shows that at variable load and fixed time (60mins), the mass of dried yam increases and the percentage moisture loss decreased due to increase in load making the heat absorption by the yam to be less as a result of increase in quantity of the yam in the dryer.

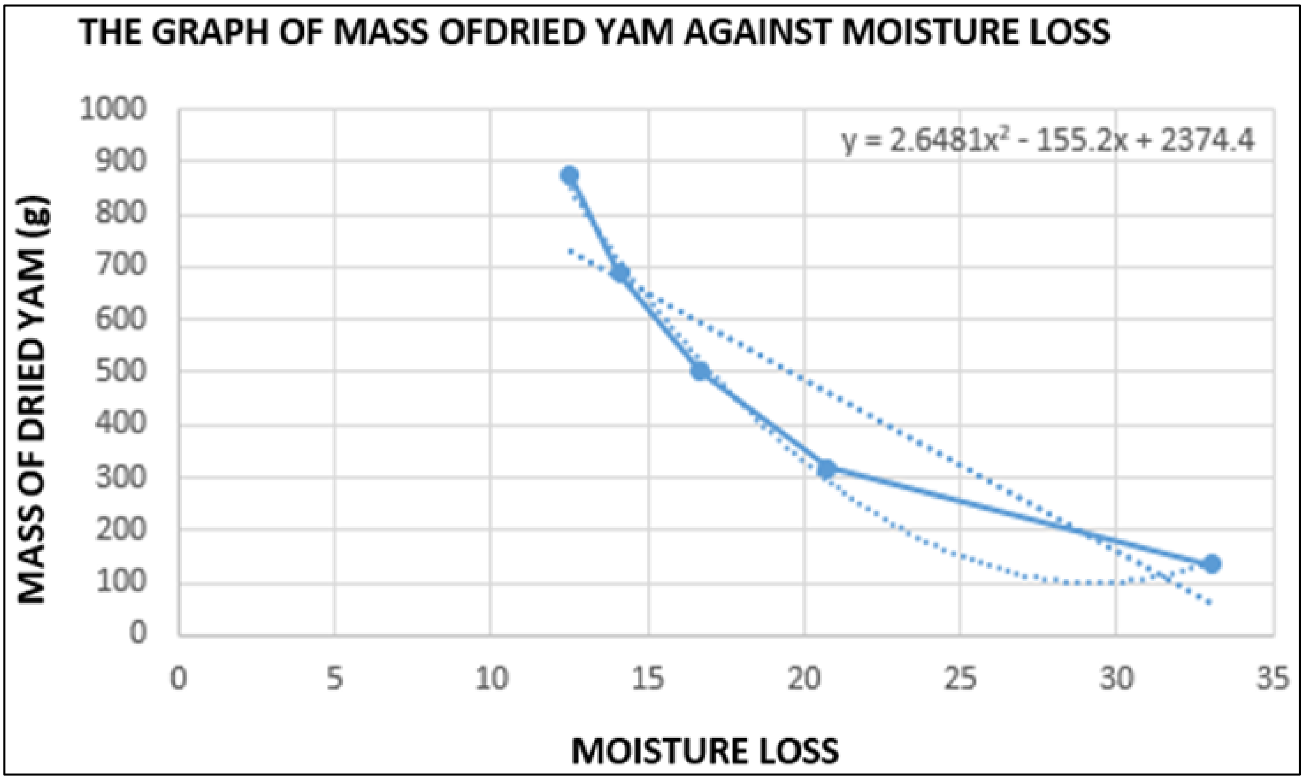


**Fig 5:** Interval plot of mass of dried yam versus moisture loss

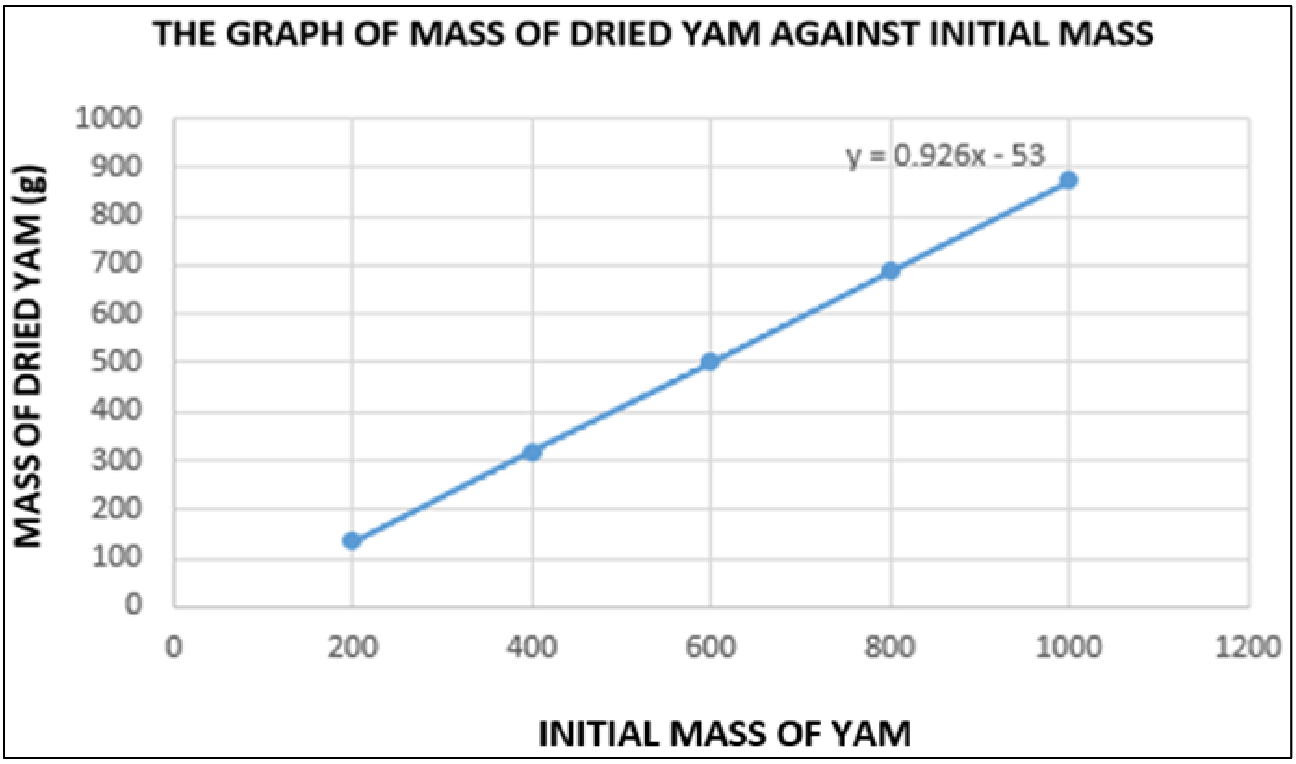


**Fig 6:** Interval plot of mass of dried yam versus initial mass of yam

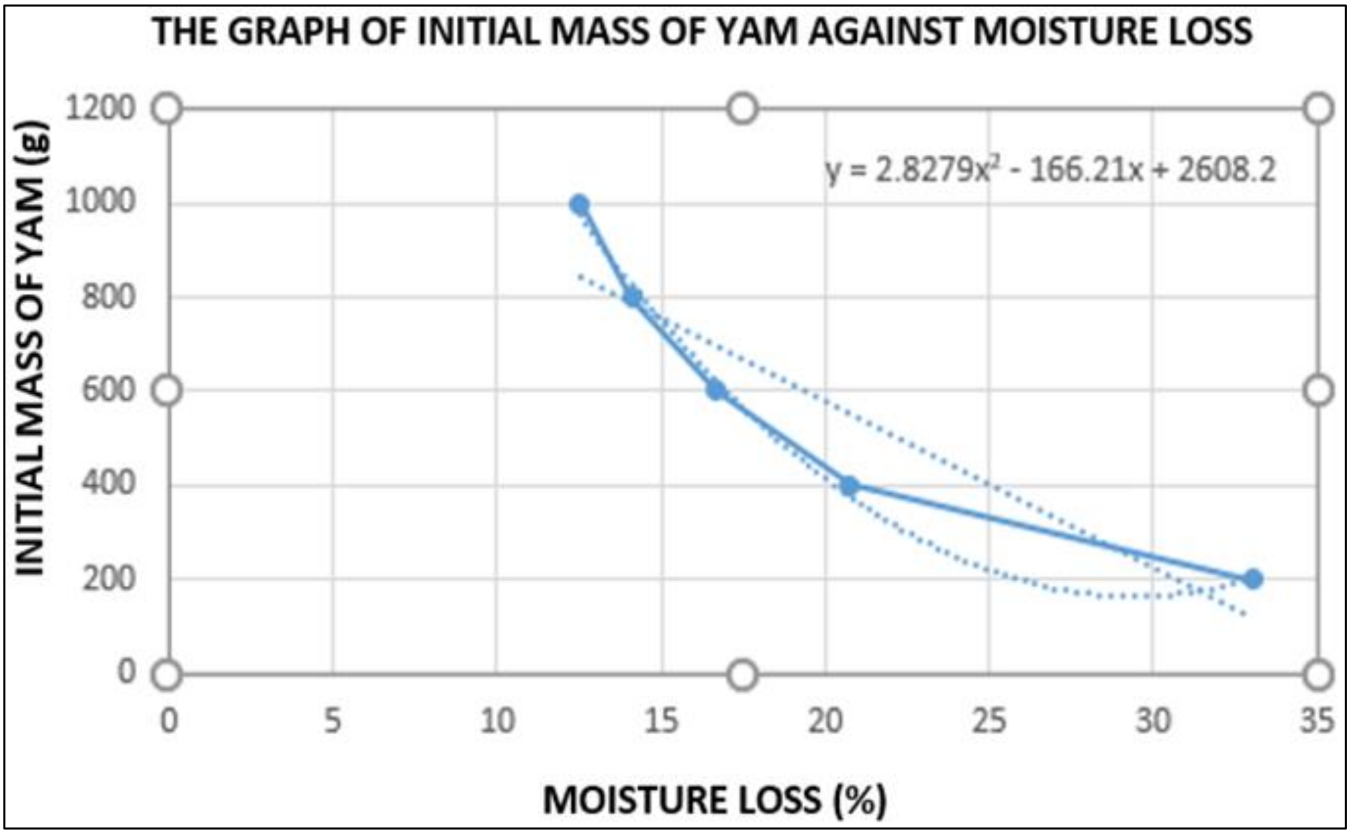


**Fig 7:** Interval plot of initial mass of yam versus moisture loss

From table 1,

**Percentage moisture content wet basis is given as**

$M_c = \frac{M_i - M_f}{M_i} \text{ x } 100$

% wet basis $Mc = \frac{500-436.8}{500} x \frac{100}{1}$

$M_c = 12.64\%$

**Percentage moisture content dry basis is given by**

$M_c = \frac{Mi-Mf}{Mf} x \frac{100}{1} = \frac{Mw}{100-Mw} x \frac{100}{1}$

% dry basis $Mc = \frac{500-436.8}{436.8} x \frac{100}{1}$

$M_c = 14.47\%$

**Drying efficiency is deduced as**

Efficiency $= \frac{wet\ basis}{dry\ basis} x \frac{100}{1}$

Drying efficiency $= \frac{wet\ basis}{dry\ basis} = \frac{12.64}{14.47} x \frac{100}{1}$

$M_c = 87.35\%$

**Amount of moisture removed $M_r$, given by**

$M_r = M_o \frac{M_i - M_f}{100 - M_f}$

Amount of moisture removed $M_r = 500\ x \frac{12.64-10.00}{100-10}$

Amount of moisture removed $M_r$ = 14.67g

**Average drying rate $D_r$, is given as**

$D_r = \frac{Mr}{t}$

Drying rate = $\left(\frac{Mr}{T}\right) = \frac{14.67}{0.67}$

Drying rate $D_r$ = 21.90g/hr

## Conclusion and Recommendation

A cabinet drying machine was designed, developed and its performance evaluated at Enugu State University and Technology, Enugu using locally sourced standard materials. The machine eliminates drudgery and tedium in the processing and production of yam flour called poundo yam as well as the excessive loss generated during the production of the desired product. The machine equally reduced the overheating (burnt) of the yam during drying process and enhanced the production of adequate quality and quantity of processed yam flour. Adoption of this machine is recommended to facilitate recycling and recycled material for further processing into any plastic product in plastic processing industries as well as its degradation of the environment.

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