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# Design, Construction and Operation of Solar Dryer for Granules and Micros Chips of *Manihot esculenta crantz* Tuberous Roots

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## Abstract

This study presents the design details and the performance analyses carried out with Eloumah 1, the solar drier of cassava tuberous roots reduced in granules and microchips. Eloumah 1 is composed by a solar collector, a drying chamber and a box of rectangular section that joins the two previous components. In this solar drier the wet agricultural products are dried on the basis of the heat flux buoyancy that is induced by the difference in temperature and humidity in its compartments. Analyses of masses evaporated water of zizila and Obama (TME 419) granules and microchips tuberous roots varieties have been carried out in order to estimate the drying performance of Eloumah 1 and to know the natural laws of the drying process. The results show that Eloumah 1 is able to dry granules and microchiphs and to reduce their moisture contain to less than 10%. Moreover, it can be established that the drying process is a logistic process because in wet control samples, moisture contain has limited value. Therefore, the drying process cannot extract the free water beyond this limit value. The logistic function adjusts well these data based on the correlation coefficient ($R^2$) and chi square coefficient ($\chi^2$).

***Keywords:*** *Manihot esculenta crantz, drying process, logistics process, drying speed function*

## 1. Introduction

Cassava (*Manihot esculenta Crantz*) is a roop crop. It process many tuberous roots in the world. These roots are used as food in several African Countries [1], South-East Asia and South America where peoples are prepared and presented them in diverse forms such as: mandioca, chikwange, fufu, malemba and many others products depending on the region, country and/or the ethnic group. Cassava tuberous roots are also an important source of income for farmers in sub-Saharan Africa, particularly in the Democratic Republic of the Congo [2]. Unfortunately, the network development of cassava in the DRC is limited by many constraints including the lack of appropriate post harvest technology. Indeed, the farmers used two traditional drying methods: open air sun drying and fire drying. Unfortunately, the final product does not comply with the relevant standards [3-5]. Solar dryers have been developed for tropical regions notably [6-11] but investment prevents their operation in the Congolese farmer country.

In the perspective of sustainable development, the operation of solar dryers designed based on locally available materials could be the most likely solution to reduce post harvests wastes. This investigation aims:

- to describe Eloumah 1, a solar dryer designed and built to dry cassava granules and microchips, in particular, the Zizila and Obama (TME 419) varieties;
- to analyze the drying process of granules and microchips in terms of evaporated mass water from a control samples;
- and to assess the residual water content of the dried control samples.

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## 2. Materials and Method

The main materials used in this study were: the natural convective solar dryer Eloumah 1; 60 control samples of cassava tuberous roots of each variety under study i.e. zizila and Obama, two varieties developed by the International Institute of Tropical Agriculture (IITA) at Mvuazi; a motorized garter (1.500 rpm), a motorized chipper (1.500 rpm), a cassava press, 1balance Metler A200, with a maximum load of 205 g and sensibility of 0.1 mg and the WW TM oven of the IITA based at Mvuazi.

### 2.1. Eloumah 1

Eloumah 1 is composed by a collector and a drying chamber of the same section. The two pieces are connected by a box of rectangular section, which diffuses the drying flux of the collector to the drying chamber. The walls are in double layers separated by a 7 cm layer of sawdust. The outer layer is made up of the transparent plastic sheets and the internal layer is plywood of 0.4 cm thickness. The bottom of the dryer is in baked bricks agglomerated with cement. To reduce heat loss, the bottom of the collector is covered with a 7 cm thick layer of sawdust on which lies gravel of the same thickness. The roof is also of transparent plastics sheets. The main face of Eloumah 1 possesses two doors that facilitate access to the pieces. The drying chamber contains six racks of 1.0 x 1.5 $m^2$ superimposed three by three in two rows. A corridor of 1.0 m wide separates the rows and facilitates loading and unloading process. The left face of the drying chamber has a small window that facilitates the handling of samples. Three wooden boxes to which are attached the thermo hygrometer sensors of the air are mounted in the dryer and outside: the first under the collector's door, the second a little bit back from the collector and the third to the left side of the drying chamber's corner. Their aeration system consists of the openings between the roof and the walls. Figure 1 shows the chart illustrating Eloumah 1.

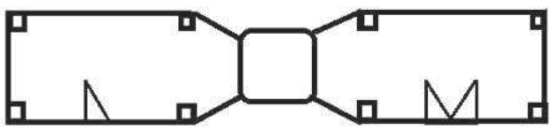

**Figure 1: The chart illustrating Eloumah 1.**

### 2.2. Control samples.

In this study, three types of control samples were used: the granules, the microchips and the chips of cassava tuberous roots. The granules and microchips were obtained by grating and chipping the peeled and cleaned tuberous roots. The granules were pressed for 15 minutes in polyurethane bag with cassava press. The microchips were soaked in water for 72 hours before being placed in polyurethane bag and pressed to reduce the moisture content between 35% and 40% before drying. Control samples were prepared by compacting granules and micro chips in 10 plastic tubes of 0.5 cm in diameter and X in length, $2 \leq X$ (cm) $\leq 6$. Each of them was replicated four times and noted as $A_i$ X, $1<i<4$. These control samples were then placed in Petri dishes of known weights. During the drying process analyze, we have used as samples the mean masses of evaporated water from control samples of each length because the product is homogenous.

Chips were obtained by cutting some tuberous roots of Zizila and Obama into pieces of thickness d, $2 \leq d$ (cm) $\leq 5$. The moist chips of each variety were loaded into 10 brown envelopes of known weights. Theirs weights named $p_e$ were $50 < p_e$ (g) $< 120$.

### 2.3. Method.

In this investigation, the collected data were needed for the further analyses. These data were: the values of the temperature, the humidity in Eloumah 1 and masses diminution of control samples.
To collect the values of temperature and humidity, two thermo-hygrometers calibrated and set in the boxes were used. Calibrated balance Metler A200 were also used for those of control samples. Using the latter, the moist control samples were weighted and then put in the drying chamber. The temperature and humidity in Eloumah 1 and its surroundings were recorded each two hours. On the same time the values of the decrease in masses of the control samples were recorded progressively by weighting them until constant weights were reached. Using these data, the curves of the distribution of temperature and humidity content in Eloumah 1 over the time were plotted (figures 2 and 3 for the temperature, 4 and 5 for the humidity) and theirs gradients were calculated by taking as origin, the centre of the collector at 0.20 cm. The mean masses of evaporated water from the control samples were calculated by using the balance mass law. These mean masses values were used to plot the dehydration curves (figures 6 and 7) using the software Origin 8. Drying parameters were also deduced from these plotted drying curves on figures 6 and 7. Finally, chips of cassava tuberous roots were dried for three days at 50°C, 70°C and 105°C for the 1st, 2nd and 3rd day in the WWR TM oven and were weighted each day. Residual moisture content was deduced by applying the law of balance mass to control samples.

## 3. RESULTS

### 3.1. Eloumah 1 characteristics.

Figures 2 and 3 are the curves of the temperature over time in the collector and the drying chamber. Figures 4 and 5 are those of humidity over time in Eloumah 1. They were obtained by fitting collected data in May 2013.

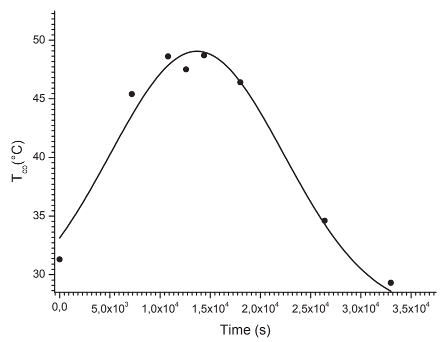


**Fig. 2: Variation of the temperature over time in the collector**

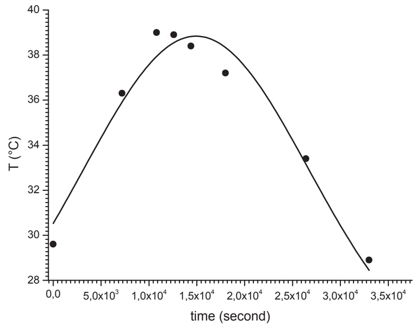


**Fig. 3: Evolution of temperature over time in the drying chamber**

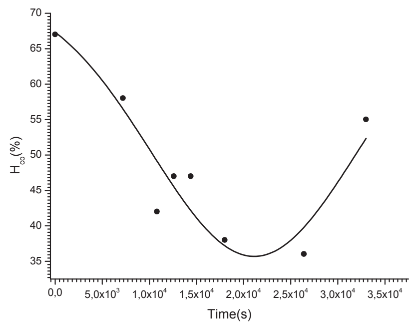


**Fig. 4: Variation of the humidity content over time in the collector**

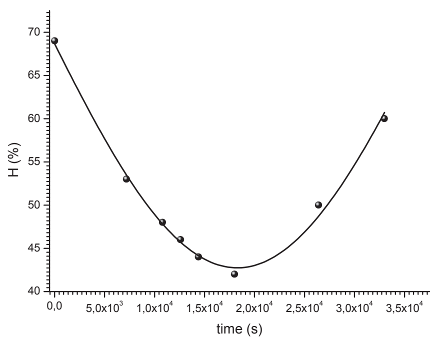


**Fig. 5: Variation of the humidity content over time in the drying chamber**

### 3.2. Drying curves of cassava samples

Figure 6 is the curve of the average of masses of evaporated water from the control samples of grated tuberous roots 6 cm long of variety Zizila over time. Figure 7 is the curve the same quantity over different lengths X

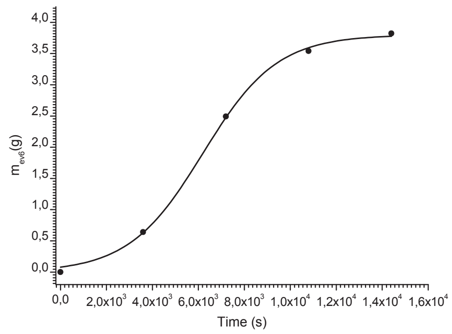


**Figure 6: Evolution of the mean masses evaporated water function $y_1$ from grated control samples of variety Zizila 6 cm long over time**

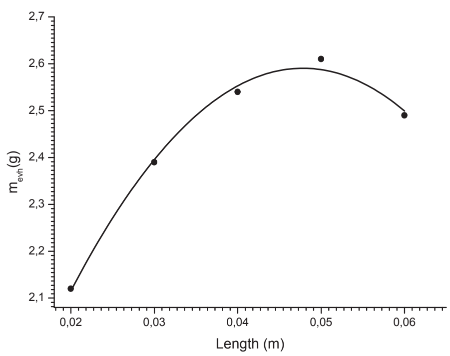


**Figure 7: Evolution of the mean masses evaporated water function $y_2$ from grated control samples of variety zizila over different lengths x.**

## 4. Discussion

### 4.1. On Eloumah 1 characteristics.

According to the curves on figures 2, 3, 4 and 5, the following observations can highlight:

- The temperature increases over the time from 31, 3 °C to 49 °C, its maximum value is reached at 1 h 17' P.M in the collector. At the same time the temperature increases from 29, 6° C to 39 °C in the drying chamber, and its maximum value is reached at 4 h 2 P.M. Therefore, between the two compartments, the difference of the observed maximum temperature reaches 10 °C.
- The humidity decreases with the time in the collector, from 67 % to 36 %, and its lower value is reached at 5 h 37' P.M while it also decreases in the drying chamber, but from 69% to 46%. This lower value is reached at 5 h 7' P.M. Therefore, the amplitude of the lower humidity between the two compartments is 10 %.

On basis of these observed differences in temperature and humidity, the thermal and humidity gradients can be defined. Table 1 summarizes the thermal and the humidity gradients in Eloumah 1 during the drying of Zizila and Obama varieties. These last gradients are inducing the buoyant force on the drying flux and this last force vaporizes molecules water during the drying process.

### 4.2. Drying process and its parameters.

Based on the correlation coefficient ($R^2$) and chi square coefficient ($\chi^2$), the logistic function defined by the relation (1) describes well the sigmoid curve on figure 6.

$$y_1 = {}^{a}/\{1 + b\exp(-kt)\} \quad (1)$$

We think that the relation (1) is really the general law of the drying process because during this process, free water intake the product is limited by the harvest witch stopping the flux. This maximum quantity ***a*** contained in it is the limiting factor. The ensuing drying cannot extract more than the remained value at harvest. Therefore, the logistic behavior [12, 13] of drying process comes from there.
Drying according to the length of the samples is described by the relation (2).

$$y_2 = me_{vh} = B_2x^2 \quad (2)$$

This last is the parabolic function with downward concavity. Figure 7 shows this function from grated control samples of zizila variety over different lengths X, $2 \leq X\ (\text{cm}) \leq 6$.
If we set $y = y_1 * y_2$ at h = x, and compare its first derivate over time with its second derivate over the length of control samples, we obtain equation (2):

$$\frac{1}{y}\cdot\frac{\partial y}{\partial t} = D\frac{\partial^2 y}{\partial x^2} \quad (3)$$

with D equal to

$$D = \frac{k}{2B_2} \quad (4)$$

Equation (3) is in the class of diffusion equation parabolic type in one dimension. Therefore, dehydration (drying process) can also be described by the law type Fick's law. In this case, the drying flux activates thermally the free water in the product that is diffused along the xylem with the coefficient D to the interface "surface of product-air drying". Free water molecules vibrate with the frequency of dehydration k. Moreover, they evaporate or they condense as the ratio of water vapor and the surface tension of dried fluid is higher or lower than one.
Table 2 summarizes constants and drying parameters of cassava varieties deducted from smoothing functions of masses of water evaporated from control samples.
The same logistic function also explains other models of drying laws notably exponential [14] and polynomial [15] laws. In the first case by using the transformation:

$$y = -\frac{(a - m_{elv})}{m_{elv}} = c * Exp(-kt) \quad (5)$$

And in the second case, by developing in series the relation (5).

### 4.3. The drying speed of the product.

To better understand what is happening during the drying, let us construct the function speed of drying and then analyze it. The drying speed of the product is defined as the first derivative by time of the logistic function (1). This is the relation:

$$V_s = \frac{V_{s0}Exp(-kt)}{[1 + b * e^{-kt}]^2} \quad (6)$$

With,

$$V_{s0} = (k * b * a) \quad (7)$$

Figure 6 is the drying speed curve of the sample 6 cm long of the zizila variety shredded over time.

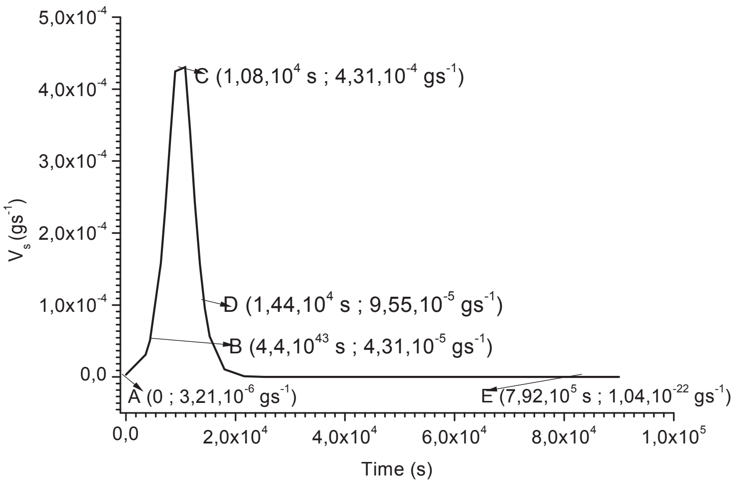


**Figure 8: Speed of drying of the 6 cm sample of the Zizila variety over time**

Figure 8 above show well four outstanding portions that correspond to the parties: AB; BC, CD and DE. For a better explain these parties, let us to write the drying speed as function of the mass of water evaporated from the control samples. We have than:

$$V_s = V_{s0}^* m_{ev}^2 exp(-kt) \quad (8)$$

With,

$$V_{s0}^* = {}^{V_{s0}}/_{a^2} \quad (9)$$

Thus, the dehydration (drying process) starts before and not at point A because the speed at this point is non-zero. Its value at point A is the natural speed of drying. Its value differs from one product to another. Ascending phase ABC corresponds to the increase of temperature in the product, which activates the free water in the product with the elimination of its fraction. The peak marks the end of temperature increase. Taking into account the relations (8), the temperature increase is proportional to the square of the mass of water evaporated. This point also corresponds to the change in concavity of the logistic function (1). It is thus an inflection point. It scored the end of temperature development and the beginning of the elimination of any free water.

The phase down CDE is corresponding to the elimination of all free water and a fraction of bound water. Taking into account the relationship (8), the elimination of water is also proportional to the square of the mass of water evaporated and so the square of temperature. Part DE is also described by logistic function and it corresponding to the elimination of a fraction of bound water. The beginning and the end of these phases are also variable from one product to another.

### 4.4. Residual moisture content of dried control samples

In the Table 3, the first and the second columns are the means average masses of wet control samples. The third and the forth columns are the evaporated water masses in the control sample of varieties dried in Eloumah1; the fifth and sixth columns represent the evaporated water masses expressed in percent. The last column is the residual moisture defined as the difference between these moistures.

We think that Eloumah 1 could be able to dry granules and micro chips of cassava tuberous roots under <10%.
Exposed in the same thermal flux in Eloumah 1, granules and micro chips of zizila variety are drying quickly than those of obama variety.

Residual moisture values in the last raw come from the intermittent nature of solar radiation the data collected day.

**Table 1: Thermal and moisture in the Solar dryer Eloumah 1 Gradients**

| t (h) | 9 h 30 | 11 h 22 | 1:00 pm | 1: 30 pm | 3:30 pm | 5:30 pm |
|---|---|---|---|---|---|---|
| $H_x$ (%$m^{-1}$) | -0.33 | 0.83 | -0.83 | -1.17 | -0.17 | -0.68 |
| $T_x$ (°$Cm^{-1}$) | 0.28 | 1.25 | 1.60 | 1.55 | 0.93 | 0.5 |

**Table 2: Drying constants and coefficients of cassava samples.**

| Variety | a (g) | b | $B_2$ $10^{-3}$($kgm^{-2}$) | $10^{-4}$ k ($s^{-1}$) | $10^{-8}$ D ($m^2s^{-1}g^{-1}$) |
|---|---|---|---|---|---|
| Granules of Zizila | 3,6±0,2 | 29±12 | -451±166 | 5,48±0,26 | 3,8±0,2 |
| Microchips of Zizila | 3,1±0,1 | 29±17 | -599±288 | 6,24±0,38 | 5,2±0,3 |
| Granules of Obama | 2.8±0,1 | 118±102 | -511±132 | 10,2±2,8 | 9,3±0,3 |

**Table 3: Residual moisture content of dried control samples.**

| Variety | $m_{01}$(g) | $m_{02}$(g) | $m_{ev1}$(g) | $m_{ev2}$(g) | $\eta_1$ (%) | $\eta_2$ (%) | $\eta_r$ (%) |
|---|---|---|---|---|---|---|---|
| Granules of Zizila | 7.15 | 81,24 | 3.66 | 47,69 | 51.24 | 58.72 | 7.48 |
| Microchips Zizila | 6.84 | 81,24 | 3.08 | 47,69 | 45.02 | 58.72 | 13.70 |
| Granules of Obama | 7.15 | 65,87 | 2.60 | 26,28 | 36.36 | 60.10 | 23.74 |

## 5. Conclusion

This investigation was demonstrated that in natural dryers such Eloumah 1 the difference of the temperature between the collector and the drying chamber induces the buoyant force on the drying flux. Eloumah 1 is a natural convection solar dryer improved because it is able to reduce the water content to that of the flour. It also protects against weather, predators and dirt dried products. The control of openings for admission and exhaust the air in Eloumah 1 remains the question how to control the browning of products drying in sunny days or overnight in bad weather. Since the solar energy, heat flux source, is inexhaustible, Eloumah 1 can be dimensioned depending on the application easily. Drying process is expectedly sigmoid and can be described by the logistic function (1). Considering the results of drying cassava tuberous root chips and granules are in concordance with those obtained by various authors in the drying of different products [15], thus, the logistic laws established above are likely the natural laws of dehydration of agricultural products.

## Nomenclature

| | |
|---|---|
| X | Tube length, cm |
| $p_e$ | Weight of moist chip, g |
| $T_a$ | Temperature ambient, °C |
| $T_c$ | Temperature in collector, °C |
| $T_{cs}$ | Temperature in drying chamber, °C |
| $T_x$ | Thermal gradient in Eloumah 1, $°Cm^{-1}$ |
| $H_x$ | Humidity gradient in Eloumah 1, $\%m^{-1}$ |
| $y_1$ | mass of water evaporated function from control over time, g |
| $a$ | total evaporated mass water from control samples by drying in Eloumah 1, g |
| $k$ | vibration frequency of water molecules from control samples on the surface of the product before evaporation, $s^{-1}$ |
| $t$ | drying time of control samples, s |
| $y_2$ | mass of water evaporated function from control over its lengths, g |
| $B_2$ | specific surface area of the control samples exposed to the drying, $m^{-2}$ |
| $x$ | damping constant dimensionless of the logistic function $y_1$, m |
| $D$ | coefficient of dehydration, either, the number of thermally excited water molecules reaching the interface unit "surface of product-air drying" per second and per unit of mass of the product, $m^2s^{-1}g^{-1}$ |
| $V_s$ | mean value of drying speed deduced the masses evaporated water function, $gs^{-1}$ |
| $V_{s0}$ | mean value of drying speed at the drying process beginning, $gs^{-1}$ |
| $\bar{V}_{s0}$ | drying speed in the beginning of the treatment, $gs^{-1}$ |
| $m_{01}$ | Means average of wet masses of varieties studied in Eloumah 1, g |
| $m_{02}$ | Means masses wet of varieties studied in the WW TM oven, g |
| $m_{0ev1}$ | Means masses of evaporated water of varieties dried in Eloumah 1, g |
| $m_{0ev2}$ | Means masses of evaporated water of varieties dried in the WW TM oven, g |

*Greek Symbols*

| | |
|---|---|
| $\eta_r$ | Residual moisture defined as the difference between the moistures of the means masses of evaporated water in the WW TM oven and Eloumah 1, % |

*Non-dimensional Numbers*

| | |
|---|---|
| $b$ | damping constant dimensionless of the logistic function |

*Notations*

| | |
|---|---|
| AiX | sample replicated |
| WWR TM | oven |
| $T_x$ | Thermal gradient |
| $H_x$ | Humidity gradient |

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