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# GRAIN SIZE AND HEAT SOURCE EFFECT ON THE DRYING PROFILE OF COCOA BEANS

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**Abstract**

***Four sweat boxes were constructed with wooden material (0.95 x 0.25 x 0.25m) L x W x H and one electric bulb with 100,200,300 and 400watts rating hoisted in each box interchangeably. Cocoa bean cleaned and sorted into four different grain sizes samples (A, B, C, D) was subjected to drying till 13-14% moisture content was achieved. In another instance, 200g of the various sizes were also dried in oven, solar dryer and direct sun. During the drying, moisture loss was monitored, humidity and temperature of the drying were determined hourly and used to determine the drying profile of cocoa by response surface and regression analysis .The moisture loss was significant among the cocoa sizes and ranged between 86.50g-114g for 400watts, and 49.9g in sample B at 100 watts. The least effective method was oven drying which recorded 13.17g moisture loss after 17 hours drying .The humidity was highest in the oven at 74.94% while the least was 61.94% on the solar drier. The sweat boxes with 400 and 300 watts were the most effective in terms of time-economy at 6 hours drying time. Sweat boxes can effectively be used to dry cocoa during heavy rains.***

***Keywords:*** Cocoa, drying, heat-source, sweatbox, grain size

## 1. Introduction

Cocoa (*Theobroma cocao L.*) is a major beverage crop in Nigeria and other West African Countries mainly for foreign trade [1]. The plant (cocoa) belongs to the *Sterculiaceae* family, with the genus *Theobroma*, consists of about 22 species cultivated and cooked, for beverage [2]. Cocoa production is mostly an SME (Small Medium Enterprise) that supports the economies of most West African families. The bean is used in confectionery, cosmetics, beverages, and pharmaceutical Industries [3]). Drying is one of the major unit operations in processing of agricultural products like cocoa [4]. Ihekoronye and Ngoddy [5] observed that drying as a process of preservation is an adequate method under most conditions in developing economies. However, drying of Cocoa is one of the major problems of small scale farmers in tropical rain forest with reference to Abia State Nigeria due to the climatic condition of the state which have relatively high sun shine and high humidity according to the report by Opeke [6].

Various methods have been advocated for cocoa drying ,among them is direct sun drying which is mostly used due to simplicity ,availability and cheap, but depends on the availability of sun, is laborious, exposes materials to dirt, rodents and environmental hazards. Solar driers are expensive for SME and also sun dependent, oven drying though secure is expensive especially when power is not steady. The use of sweat boxes which is an improved artificial method can be used by farmers, however, the rating of the power sources and established construction standard is not available. More so, Sahay and Singh [7] have reported that grain sizes and cocoa bean internal friction affects the flowability of bulk product due to irregularities.

Therefore, the successful design and evaluation of a standard low cost sweat box which will use low power electric generators will go a long way saving farmers from excessive post-harvest losses in cocoa during peak harvest periods and heavy rains of April- October. The display of the drying profile of cocoa using the various methods will help to compare between them.

### *1.1 Theory of Drying*

Drying is a convection process in which moisture from a product is removed and therefore can be regarded as a heat and mass transfer process [8]: the moisture could be either bound or unbound. Sahay and Singh [7] have reviewed various drying methods, drying rate periods and found that drying rate period is a function of products moisture content. During drying process, movement of moisture inside a porous product could be due to capillary flow, diffusion (surface, liquid or vapour), and thermal or hydrodynamic flow [9]. Many investigation on drying process have been conducted based on the theories of moisture/

diffusion through capillaries of grains. Various drying models as reported by Sahay and Singh [7] have been developed for capillary porous product in partial differential equation form as below

$$\frac{\partial m}{\partial \theta}=V^2 K_{11}M + V^2 K_{12}t + V^2 K_{13}P \quad (1)$$

$$\frac{\partial t}{\partial \theta}=V^2 K_{21}M + V^2 K_{22}t + V^2 K_{23}P \quad (2)$$

$$\frac{\partial P}{\partial \theta}=V^2 K_{31}M + V^2 K_{32}t + V^2 K_{33}P \quad (3)$$

In simplified form, the equation becomes

$$\frac{\partial m}{\partial \theta}=V^2 K_{11}M \quad (4)$$

$$\frac{\partial t}{\partial \theta}=V^2 K_{22}t. \quad (5)$$

Where M=Moisture Content %(db), $\theta$ =time, hr, t=temperature $^oC$

The moisture migration within a grain (bean) is mainly because of liquid and or vapour diffusion, the transfer coefficient $K_{11}$ of equation 4 is replaced by diffusion coefficient ($Dv$), so we have therefore

$$\frac{\partial m}{\partial \theta} = Dv[\frac{\partial^2 M}{\partial r2} + \frac{c\partial M}{rdr}] \quad (6)$$

C =0 for planar symmetry, C=1 for cylindrical body, C=2 for sphere (cocoa bean).

If boundary conditions are taken then: $M(r,0) = Mo$ (initial moisture content) and $M(ro,0) = Me[EMC]$, where r is the radius of the cylinder or sphere, then the equation becomes,

$$\frac{M-Me}{Mo-Me} = \frac{8}{\pi^2}\sum_{n=0}^{\infty}\frac{1}{(2n+1)^2}\exp[-\frac{(2n+1)^2\pi^2}{4}x^2] \quad (7)$$

and for a spherical body such as cocoa bean

$$\frac{M-Me}{Mo-Me} = \frac{6}{\pi^2}\sum_{n=0}^{\infty}\frac{1}{n^2}\exp[-\frac{\pi^2 n^2}{9}\ x^2] \quad (8)$$

But a simple drying equation based on newton's equation was composed as follows

$$\frac{dm}{d\theta} = -K(M - Me) \quad (9)$$

Where M is the moisture content, $\theta$ is the time in hours, Me= EMC % (db) and K is the drying constant.

$$\therefore \frac{dM}{M-Me} = -Kd\theta \quad (10)$$

By integrating between limits M(r,0) =M, initial moisture content and $M = (ro,0) = Me$,(EMC) we get;

$$\frac{M-Me}{Mo-Me} = \exp(-k\theta) \text{ or } \theta = \frac{1}{k}ln\frac{M-Me}{Mo-Me} \quad (11)$$

## 2. Materials and Methods

### *2.1 Description of Sweat Box*

The sweat box consist of a wooden box (0.25 x 0.25 x .90 m)(WxHxL) constructed on a wooden stand (0.95 x 0.65m)LxH, on top of the wooden box is plywood with thickness, perforated for air ventilation in the middle of the surface of the plywood, an electric bulb is hoisted for the various 4 boxes. The bulb varied between 100, 200, 300 and 400 watts capacity. The bean is on the lower part of the wooden box in a drawer which is constructed with plywood that serves as the drying trays (0.036 x 0.2 x 0.25m). Figure.1 is the orthographic side and top views of the sweat box.

### *2.2 Projected Sweat Box*

Considering the experimental sweat box, construction of a projected sweat boxes could be achieved based on the following relationship.

$$V_p = nV_E \quad (12)$$

$$N_bP = n\sum B \quad (13)$$

Where $V_p$ is the Projected Volume of Sweat Box, $m^3$, $V_E$ is the Experimented Volume of Sweat Box, $m^3$, $N_bP$ is the Projected number of electric bulbs, $\sum B$ is the Experimented number of electric bulbs while n is the number of magnification; 1, 2, e.t.c

## 3. Design Considerations

The following were considered in the design, the easy measurement of temperature and other parameter. Refraction to aid air circulation, low cost of material and light material for easy carriage, easy dismantling and easy product removal

### *3.1 Experimental Procedure*

The cocoa pods were procured from Umuariga Oboro, Ikwuano L.G.A. The pods were depoded and kept in a basket for 3 – 5 days for fermentation to occur. The fermented bean seeds were sorted and graded into four particles sizes A, B, C and D as follows

*Table 1. Physical Measurement of the cocoa bean*

| Sample Number | Thickness (L)mm | Width (w) mm | Height (h)mm |
|---|---|---|---|
| A | 07.00 – 08.00 | 10.00 – 11.00 | 17.00 – 19.00 |
| B | 10.00 – 11.00 | 11.00 – 12.00 | 21.00 – 23.00 |
| C | 08.00 – 09.00 | 13.00 – 14.00 | 23.00 – 25.00 |
| D | 09.00 – 10.00 | 12.00 -13.00 | 19.00 – 21.00 |

The various particle sizes were subject to thermo physical properties measurement such as density, thermal-conductivity, and specific heat. Two hundred grammes of each sample size were dried by oven drying, Sun drying, Solar and Sweat box drying at the various electric bulb capacities by placing the beans on a constant weight tray which then was placed using the dryers respectively. The temperature of the dryer, the beans were measure before and after every hour drying time until 14% moisture level were achieved by a 4 way Thermocouple Omega HHT.

The humidity of the drying was determined hourly by humidity meter model IT 202-Thermometer W/Hygro clock while drying time was monitored by a stop watch (hrs). After each hour drying, the sample was removed and reweighed in a chemical balance, the difference in weight was used to determine the moisture loss for the drying time [10]. The drying was continued until a moisture of 14% or less were achieved for that bean size and drying method.

### *3.2 Data Analysis.*

Data on moisture loss, average humidity and drying time or difference in temperature per each drying method for each cocoa bean size was subjected to Multiple regression analysis, drying curves and response surface plots were used to explain the drying profile while analysis of variance was used to establish differences by using Matlab 6.5 software. The regression model took the linear form:

$$M = b_0 + b_1k + b_2h + b_3t + b_4kh + b_5kt + b_6ht + e \quad (14).$$

Where M=moisture loss

K,h and t are change in temperature, humidity and drying time respectively.

$b_0$=constant of regression, $b_1$, $b_2$ and $b_3$are variable coefficients due to change in temperature, humidity and drying time respectively, while $b_4$, $b_5$ and $b_6$ are the coefficients due to their interactions.

## 4. Results and Discussion

The result in Table 2 is the statistical analysis of data showing the moisture loss, change in temperatures, average relative humidity and drying time for sample A for the various heat or drying methods. There was no significant difference in moisture loss among the used sweat boxes but moisture loss differed in the other drying methods, with oven drying the poorest, while sweat box with 400 watts bulb capacity displayed the highest moisture loss at 114 $\pm$10.0 g. Among the boxes the change in temperature was less in the 100 watts and difference existed in the change in temperature. Among the drying methods, oven drying too revealed the less change in temperature at 7.12 $^0$C.Considering the change in temperature in the sweat boxes with 300 and 400 watts which ranged between 25 to 32 degrees, one could observe that the drying temperature of 50 to 60$^o$C were achieved if the room temperatures were between 25 -27$^o$C. This regime complies with investigation by Sahay and Singh [7]) that drying could be achieved at temperatures between 60 to 70$^o$C, while Asiedu [11] noted that a layer of cocoa beans 25cm deep with air flow of 3m$^3$ /mins at temperature of 60-65$^o$C gave the most economic conditions..

The average relative humidity was least in the solar dryer at 62.78%, while the highest was in the oven at 79.94% but this did not differ from sweat box at 300 and 400 watts. The drying time as shown on the table varies and is dependent on humidity, temperature change, while the sun drying achieved the moisture loss of 13.42 g by 19 hours. This is long compared to other methods. These trends are similar to what happens in other samples of B,C and D as shown in table 3,4,and 5 respectively

Table 6 shows the regression analysis on the various samples, the positive coefficients indicates that the factor in question affects positively the moisture loss, while those with negative do not support moisture loss In this case the higher the initial moisture content, the slower the rate of loss. Sahay and Singh [7] have shown the relationship between moisture and rate of drying based on Newton's equation (equ.9).And also drying rate period have been found to increase with increase in moisture. The table further revealed that coefficient of temperature, time and humidity were positive except for sample A, while their interaction were negative This recent development have confirmed the fact that size of grain is a factor in drying.

*Table 2 : Moisture loss, change in temperature, average relative humidity and drying time of cocoa bean (sample A)*

| Drying methods | Moisture loss (g) | Change in temperature ($^0$C) | Average relative humidity (%) | Drying time (hrs) |
|---|---|---|---|---|
| Sweat boxes 400watts bulb | $114.00 \pm 10.13^a$ | $32.00 \pm 0.73^a$ | $69.83 \pm 0.71^{ab}$ | 6 |
| Sweat boxes 300watts bulb | $109.67 \pm 10.72^a$ | $30.33 \pm 0.98^a$ | $74.25 \pm 0.83^a$ | 6 |
| Sweat boxes 200watts bulb | $107.14 \pm 12.72^a$ | $14.86 \pm 1.75^b$ | $70.71 \pm 15^{ab}$ | 7 |
| Sweat boxes 100watts bulb | $102.14 \pm 8.42^a$ | $10.50 \pm 0.85^c$ | $70.19 \pm 0.64^{ab}$ | 8 |
| Sun drying | $13.42 \pm 2.44^c$ | $3.32 \pm 0.40^e$ | $64.66 \pm 2.41^{bc}$ | 19 |
| Solar drying | $39.56 \pm 12.31^b$ | $14.67 \pm 1.62^b$ | $62.78 \pm 1.21^c$ | 9 |
| Oven drying | $11.18 \pm 1.88^c$ | $7.12 \pm 0.67^d$ | $74.94 \pm 0.78^a$ | 17 |

$^{a-e}$ means in the same column with different superscripts are significantly different ($p \leq 0.05$ level of significant).

*Table 3: Moisture loss, change in temperature, average relative humidity and drying time of cocoa bean (sample B)*

| Drying methods | Moisture loss (g) | Change in temperature ($^0$C) | Average relative humidity (%) | Drying time (hrs) |
|---|---|---|---|---|
| Sweating boxes 400watts bulb | $86.50 \pm 19.96^{a}$ | $27.00 \pm 3.04^{a}$ | $70.25 \pm 0.60^{ab}$ | 8 |
| Sweating boxes 300watts bulb | $77.88 \pm 17.88^{ab}$ | $25.13 \pm 1.93^{a}$ | $70.94 \pm 0.82^{b}$ | 8 |
| Sweating boxes 200watts bulb | $59.89 \pm 15.01^{abc}$ | $15.22 \pm 1.30^{b}$ | $72.11 \pm 0.46^{ab}$ | 9 |
| Sweating boxes 100watts bulb | $49.90 \pm 12.03^{bc}$ | $10.10 \pm 0.60^{c}$ | $71.10 \pm 0.62^{b}$ | 10 |
| Sun drying | $13.58 \pm 1.52^{d}$ | $3.37 \pm 0.43^{d}$ | $65.45 \pm 1.51^{c}$ | 19 |
| Solar drying | $36.00 \pm 9.91^{cd}$ | $14.89 \pm 1.71^{b}$ | $62.56 \pm 1.09^{c}$ | 9 |
| Oven drying | $10.35 \pm 1.78^{d}$ | $7.12 \pm 0.67^{c}$ | $74.94 \pm 0.78^{a}$ | 17 |

$^{a-d}$ means in the same column with different superscripts are significantly different ($p \leq 0.05$)

*Table 4 Moisture loss, change in temperature, average relative humidity and drying time of cocoa bean (sample C)*

| Drying methods | Moisture loss (g) | Change in temperature ($^0$C) | Average relative humidity (%) | Drying time (hrs) |
|---|---|---|---|---|
| Sweat boxes 400watts bulb | $101.33 \pm 19.35^{a}$ | $29.67 \pm 1.71^{a}$ | $69.58 \pm 0.15^{b}$ | 6 |
| Sweat boxes 300watts bulb | $93.57 \pm 13.86^{a}$ | $30.57 \pm 1.15^{a}$ | $69.71 \pm 0.47^{b}$ | 7 |
| Sweat boxes 200watts bulb | $89.13 \pm 13.38^{ab}$ | $18.38 \pm 0.51^{b}$ | $71.63 \pm 0.18^{ab}$ | 8 |
| Sweat boxes 100watts bulb | $65.89 \pm 11.87^{b}$ | $14.56 \pm 1.53^{c}$ | $68.00 \pm 0.92^{bc}$ | 9 |
| Sun drying | $13.89 \pm 2.80^{c}$ | $3.63 \pm 0.44^{e}$ | $65.87 \pm 1.36^{cd}$ | 19 |
| Solar drying | $33.89 \pm 8.73^{c}$ | $13.78 \pm 1.51^{c}$ | $62.72 \pm 1.18^{d}$ | 9 |
| Oven drying | $13.94 \pm 2.45^{c}$ | $7.12 \pm 0.67^{d}$ | $74.94 \pm 0.78^{a}$ | 17 |

$^{a-e}$ means in the same column with different superscripts differ significantly ($p \leq 0.05$)

*Table 5: Moisture loss, change in temperature, average relative humidity and drying time ofcocoa bean (sample D)*

| Drying methods | Moisture loss (g) | Change in temperature ($^0$C) | Average relative humidity (%) | Drying time (hrs) |
|---|---|---|---|---|
| Sweat boxes 400watts bulb | $94.83 \pm 14.09^{a}$ | $31.17 \pm 1.59^{a}$ | $68.92 \pm 0.35^{bc}$ | 6 |
| Sweat boxes 300watts bulb | $90.17 \pm 13.92^{a}$ | $30.83 \pm 1.25^{a}$ | $71.25 \pm 0.42^{b}$ | 6 |
| Sweat boxes 200watts bulb | $90.86 \pm 14.62^{a}$ | $29.29 \pm 1.41^{a}$ | $71.00 \pm 0.22^{b}$ | 7 |
| Sweat boxes 100watts bulb | $81.38 \pm 12.73^{a}$ | $13.50 \pm 2.16^{b}$ | $68.75 \pm 0.73^{bc}$ | 8 |
| Sun drying | $14.94 \pm 2.83^{b}$ | $3.53 \pm 0.48^{d}$ | $65.81 \pm 1.33^{c}$ | 19 |
| Solar drying | $33.78 \pm 9.23^{b}$ | $13.44 \pm 1.45^{b}$ | $61.94 \pm 1.09^{d}$ | 9 |

*Table 6: Regression Table for the Drying Method*

| Samples | Regression coefficients | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|
| | $B_o$ | $B_1$ | $B_2$ | $B_3$ | $B_4$ | $B_5$ | $B_6$ | P | R |
| A | 1143 | 2.54 | -13.9 | -86.5 | 0.156 | -2.56 | 1.25 | 0.031 | 99.8 |
| B | -2504 | 116 | 36.0 | 97.3 | -1.46 | -1.56 | -1.33 | 0.041 | 98.0 |
| C | -2127 | 61.5 | 32.3 | 106 | -0.873 | -0.048 | -1.61 | 0.014 | 97.8 |
| D | -2717 | 53.5 | 33.5 | 116 | -0.799 | 0.316 | -1.79 | 0.032 | 96.8 |

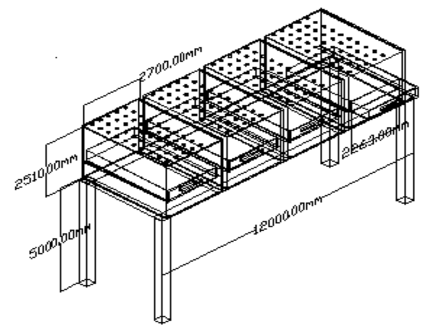
For key, refer to data analysis

The regression equation representing the moisture loss, M is:

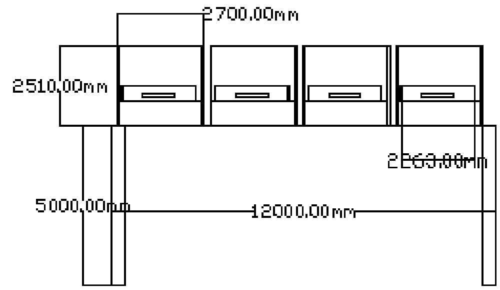
$$M = 1143 + 2.54k - 13.9h - 86.5t + 0.156kh - 2.56kt + 1.25ht \quad (15)$$

where k is the change in temperature, t is the time, h is the humidity, kh is the interaction of humidity and change in temperature and kt is the interaction of change in temperature and time

The model adequacy analysis above shows that the factors and their interaction are significant because their P-values are less than 0.05 and that the condition is adequately described by the model (Equation 15), since the point prediction of the Mathlab software depicts zero residue for each actual experimental point and their prediction from the developed model (Equation 15). The surface graphs based on the interactions of the variables in the experiment is shown in Figures 3, 4, 5 and 6.




*(a) Isometric view*




*(b) Side view*

*Figure 1: Views of the sweat sweat box*

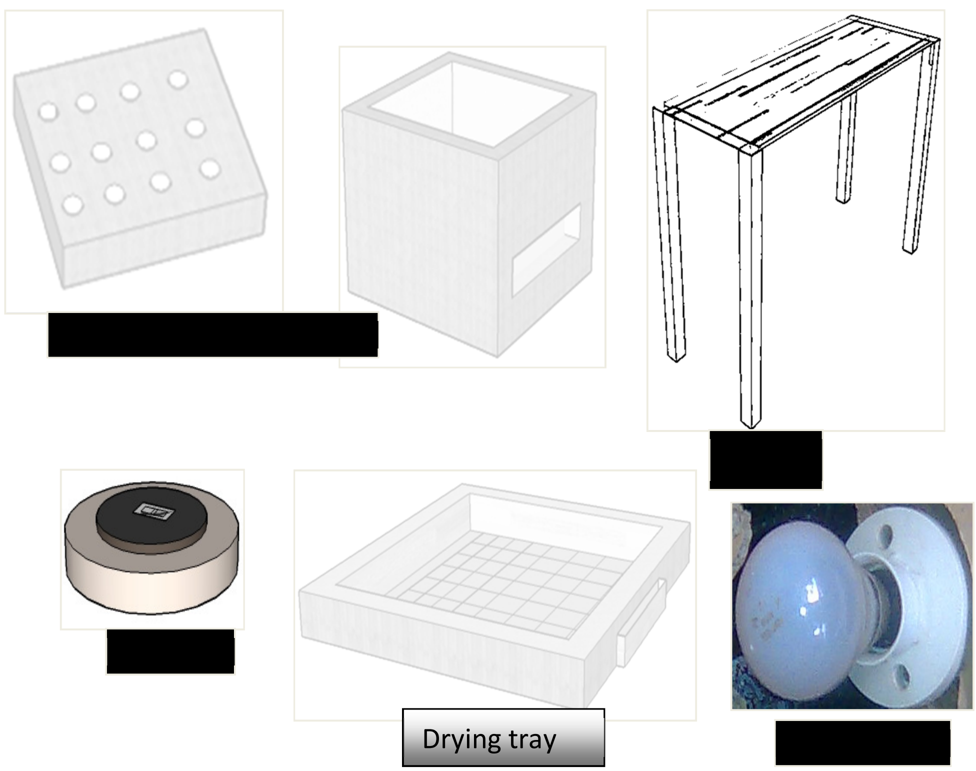



*Figure 2 Pictorial view of components of the sweat box*

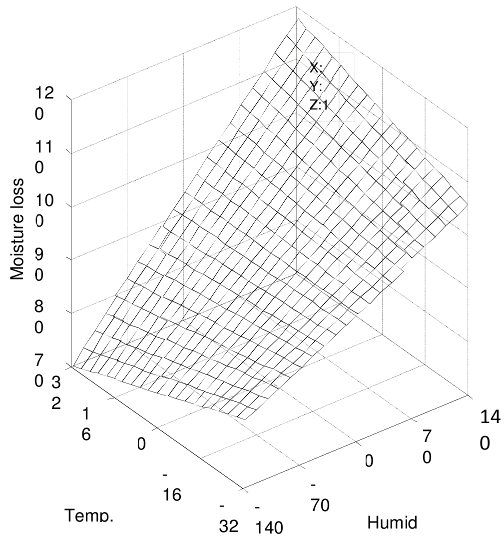



*Figure.3: Surface plots showing the effect of temperature and humidity on the drying of sample A of cocoa beans*

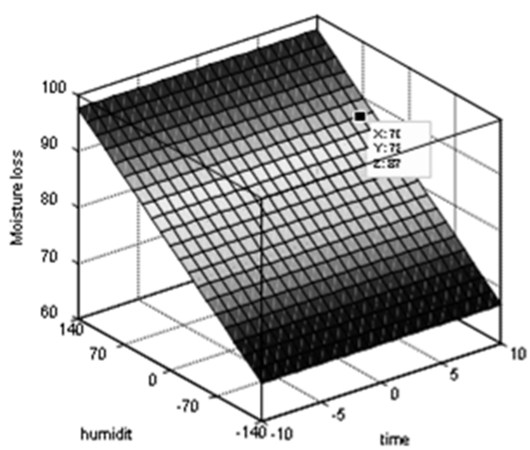



*Figure.4: Surface plots showing the effect of humidity and time on the drying of sample B*

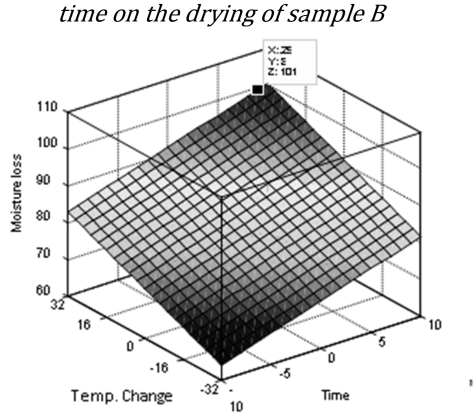



*Figure 5: Surface plots showing the effect of temperature and time on the drying of sample C of cocoa beans*

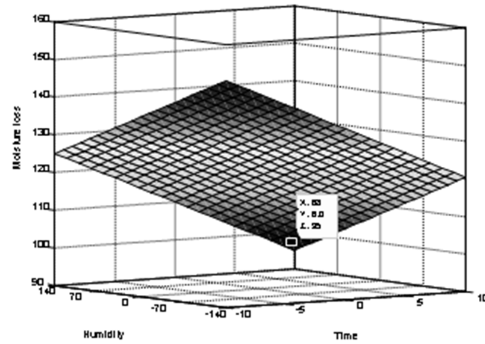



*Figure.6 Surface plots showing the effect of humidity and time on the drying of sample D*

The moisture in the sweat boxes had a better result compared to other drying methods; thus the drying efficiency of the cocoa beans which was best in the sweat box was followed by solar drying before sun drying and oven drying. Generally all the processes showed a rising constant drying and then a slow or falling drying section, which is in conformity to the report by Ihekeronye and Ngoddy [5]. See the surface plots of figures 2-6 .All the plots showed that the higher the temperature change the higher the moisture loss, and that the higher the humidity the longer the drying period

Sun drying and oven drying did not have a sharp moisture loss at the beginning of drying due to high humidity and low temperature of the rainy season for the sun drying, while high humidity in the ovens made the seeds absorb moisture instead of losing it. This is in line with the finding of Denis and Singh[12] that the capacity of dry air to remove moisture from agricultural materials depends on the humidity of the air, while Ihekeronye and Ngoddy[5] have reported the adsorption of agricultural material as results of environmental factors such as temperature ,water vapour pressure etc, so drying of cocoa bean in the sweat boxes increased with increase in time and heat (that is heat flow kept increasing as time interval of the drying was increasing) and so leading to speedy rate of moisture loss but solar dryer maintained an ideal rate of drying prior to temperature change and relative humidity of its environment as stated by Sahay *et al.,* [13].

However, sun drying was affected by unstable sunlight due to weather conditions, but gradually increased the drying rate as the day gets by and as heat is absorbs from the radiated sun, though sun drying is cheaper but presents the products with an unacceptable colour and texture.

Oven drying had steady supply of heat but slow rate drying and unacceptable colour and texture, had a long duration of time and can't remove moisture to a safe limit within a short time when compared with sweat boxes and solar drying. This was due to the high humidity displayed in oven drying.

In temperature change, sweat boxes of 400 watts and 300 watts power ratings were the best and significantly differed from 100 watts, sun drying and oven drying respectively. This according to report credited to Ihekoronye and Ngoddy [5], which stated that as temperature raises, the Brownian movements get faster and beans dry faster. Kouchakzdeh and Ghobodi [14] used 150 and 300 watts ultrasonic convective dryer while here we have used 100 – 400 electric power, and both systems proved effective

With 200 watts in the sweat boxes and solar drying were better than the 100 watts of sweating box, oven drying and sun drying respectively due to their increased temperature which affected the duration of drying time thereby making it shorter and faster which agrees with Arinze *et al*, [15] that quicker drying within a short period is said to be effective and the problem of oven drying does not occur which causes a reduction in dry matter and increase in energy cost.

For Average relative humidity, it was observed that the relative humidity in solar dryer is low and that solar dryer is the best for Sample A, followed by sun drying, sweat boxes and oven drying because the lower the average relative humidity of drying environment, the higher the temperature and rate of moisture loss, thus less time consumed in drying, as quick drying prevents chemical processes which starts during fermentation [16].

Thus in tables 2-5 it was observed that the rate of moisture loss and temperature change in all samples with time at different power ratings of the sweating box, that less time was used in drying the samples in the 400 watt and 300 watt compared to 200 watt and 100 watts; thus 400 watt and 300 watt rated sweat boxes were the best because of the less drying time which as predicted was achieved due to high moisture loss and high temperature which affected drying rate periods of the samples, this agrees with Brooker *et al*, [17] which states that in the predicted drying time of biomaterials; the drying rate is an important factor with respect to drying temperature

## 5. Conclusion

This research has shown that farmers can dry cocoa bean successfully during the rainy seasons using the sweat boxes powered by electric bulbs via low power generating sets .The drying profile of cocoa under the various methods has been determined and the data produced in this work can be used in the design of cocoa dryers.

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