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Evaluation of a cabinet dryer developed for cassava chips

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Abstract

Drying is a very important unit operation in the processing of fresh cassava root tubers into chips because it forestalls unprecedented and, sometimes, incalculable amount of losses often incurred by cassava farmers and processors due to spoilage and massive reduction in quality, and by extension, income. This study aimed at evaluating the performance of a prototype sawdust- fueled and fan-forced convection cabinet dryer developed for cassava chips. The specific objectives were to develop regression equations to relate drying (or elapsed) time and moisture content for sun drying and drying of fresh peeled cassava chips on each of the three trays of the cabinet dryer. The dryer was evaluated by testing with 4.5 kg of fresh peeled cassava tuber chips. Regression equations were developed to relate percentage moisture contents of the drying cassava chips and elapsed (or drying) time for the two types of drying media. While it took 16 hours to sundry 4.5 kg of the peeled cassava chips to a safe moisture content of 13.9 % w. b. during the humid raining season month of August, it took only 3 hours to bring the same mass of peeled fresh cassava chips to an average safe moisture content of 12.2 % w.b. when placed in the cabinet dryer during the same period of the year implying that there was a 15 hour (or 83.3 %) reduction in time required to dry the same quantity of the fresh peeled cassava chips to a safe moisture content when the cabinet dryer was used.

Keywords: Cassava Chips, Cabinet dryer, Forced Convection, Sun drying, Regression analysis, Polynomial model.

Introduction

It is extremely difficult to argue against the many advantages of sun drying of crops because it is easy to control, almost completely fire safe, and rarely if ever, is the crop being dried harmed at least from the standpoint of the layman. For these reasons it is easy to understand why sun drying has been popular with farmers in Nigeria and most other developing tropical countries of Africa.

However, despite all these advantages, sun drying has some significant disadvantages. The greatest of these probably is its dependence on weather conditions with consequent wide fluctuation in drying time(Nanda et al.,2002). Under ideal conditions of high ambient temperature and low relative humidity, such as we have in the daytime during the harmattan season in Nigeria, it is reasonably fast and efficient. Unfortunately, however, throughout most of the states leading in agricultural production in Nigeria, nature does not often provide these ideal conditions when needed the most(FIIRO, 2006). A typical case in point is that of Nigerian cassava producing farmers. At the time when the weather is very favorable for sun drying of cassava chips (i.e during the harmattan season which is usually between October and March), the soil is usually very hard due to lack of moisture in the soil. This is a condition that makes cassava harvesting to be very difficult, relatively more expensive and inefficient regardless of whatever method is used; a lot of cassava root tubers get abandoned in the soil in advertently. Conversely, when the soil is soft and weather is humid (as it is often the case during the raining season which runs between March and October), cassava harvesting is usually much easier and cheaper but difficult to sundry as a result of low ambient temperature and high relative humidity. This means that the farmer has only partially freed himself from the vagaries of nature(Taiwo, 2012).

Coupled with this slow, uncertain drying rate is the fact that the farmer or processor is limited as to how he can go about reducing the moisture content of the crop. For long-term storage of cassava chips where low moisture content is necessary for the prevention of spoilage, sun drying cannot produce sufficiently low relative humidity to do the job even under the best drying conditions(Alonge and Adeyemi, 2009).

A review of the past history of heated air drying revealed that it made its start from large scale commercial operations, such as in tower silos with bucket elevators, screw conveyors, etc. Since time was a prime factor in this type of operations, with the tremendous quantities of wet farm products involved, it was logical that high temperature be applied. Furthermore, most drying of this type was done in a continuous –flow operation, exposing the produce to the high temperature for only a definitely limited period of time and then in a thin bed to minimize moisture content stratification. With this method, accurate control of necessary parameters and high drying rate could only be achieved without danger to the product being dried under the direction of experienced personnel (Sethi, 2007).

Conditions on the farm are quite different, however, particularly in terms of the material-handling equipment and experienced drying personnel. It is not surprising, therefore, that past experience in using large quantities of heat- for example, 30 to 45 liters of fuel oil per hour has shown many cases of over dried and unevenly crops. Furthermore, there is a greater degree of danger due to fire outbreak in the case of high rates of fuel consumption by untrained or low-skilled personnel.

Considering the requirements of a typical farm crop dryer, first and formost, it must be designed to dry a number of different crops with entirely different physical characteristics. It must be able to dry these crops in large or small amounts and in beds of varying thickness. It would be impractical from both the standpoint of manufacture and customer use, to design and build many different models of crop dryers (Dorn, 2009).

To accomplish the above stated objective, a prototype cabinet dryer developed in a previous research effort was equipped with a centrifugal fan powered by a single phase 2.2 kW electric motor to provide reasonably good air delivery over a range of static pressures from 2.5 to 6.4 mm of water column into the cabinet dryer through the heat exchanger w. The heat input was also variable over a wide range, say, 0.5 to 1.5 or 2 kg of dry saw dust per hr per kg

of dried cassava chips (Taiwo, 2009).
Since heated- air drying using a moderate amount of heat has been criticized as not fast enough, it is the aim of this study to evaluate the performance of the afore-mentioned cabinet dryer developed for cassava chips. The objectives were to develop regression equations to relate drying (or elapsed) time and moisture content for sun drying and drying of fresh peeled cassava chips on each of the three trays of a dry saw dust fueled and forced convection cabinet dryer .

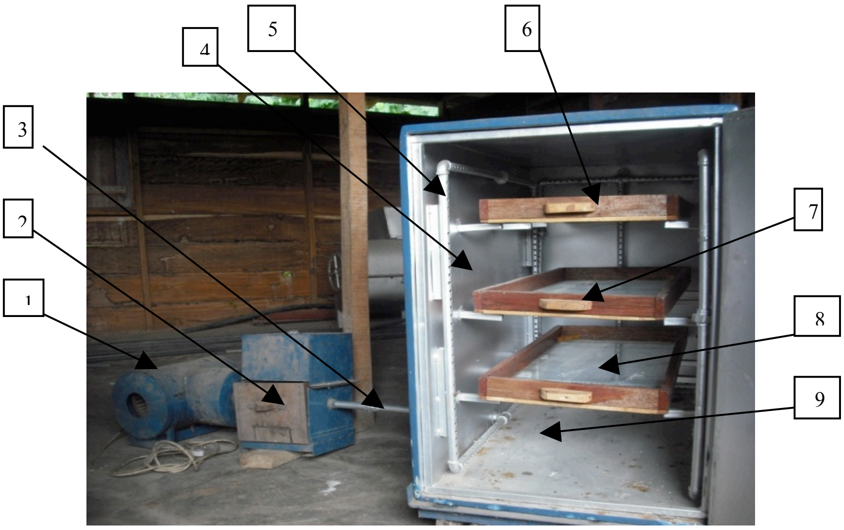

Figure 1: Fan/Furnace/Heat exchanger Assembly and Layout of Cabinet dryer Interior
1-Centrifugal fan, 2-Furnace/Heat exchanger assembly, 3-Dryer cabinet inlet, 4-Insulated dryer cabinet wall, 5- Perforated pipe, 6- Tray 3, 7- Tray 2, 8- Tray 1, 9-Insulated dryer cabinet floor.

Materials and Methods

The effect of elapsed time on percentage moisture content of cassava chips loaded on each of the three drying trays of the cabinet dryer was used to evaluate the performance of the cabinet dryer when fired by saw dust (Figure1). These performance data were later compared with those obtained from sun drying.

Both the experimental and laboratory analyses for the project reported in this paper were carried out in the Crop Processing Laboratory of the Agricultural Engineering Department of the Ladoke Akintola University of Technology (LAUTECH), Ogbomoso, Nigeria . The cassava specimen which has an initial moisture content of 71 .71 % (wet basis) when chipped was obtained from the LAUTECH Teaching and Research Farm . The safe moisture content for dried Cassava chips is between 12.6 – 14% (Alonge and Adeyemi, 2010).

Materials

The materials and apparatus used were:
i. Fresh cassava tuber (*Manihot escuelenta cranz*) (71.71% moisture content wet basis)
ii. Tropical Engineering- developed ‘Continuous-flow Rotary Cassava chipper.’

iii. Micrometer Screw Gauge (Super Tek 0 – 25mm).
iv. Water, trough and basket (to drain out water).
v. Psychrometric Chart.
vi. Wet and Dry bulb thermometer.
vii. Mercury bulb thermometers (0ºC - 360ºC).
viii. LAUTECH-developed 'Cassava chips Cabinet dryer.'
ix. Stop watch (Precista 7 Jewel, Swiss made).
x. Weighing scale 0 – 10kg (Camry made).
xi. Saw dust.

Description of the cabinet dryer

The drying chamber of the cabinet dryer has all its three walls, door, roof and floor insulated. A network of perforated pipes are arranged on three walls of the chamber as shown Figure1 to avoid moisture stratification in the drying product. The 50 mm diameter exhaust pipe of the dryer is located on the upper part of the rear wall of the chamber to serve the purpose of carrying out the moisture laden air from the dryer . Three pairs of dowels are welded to each sidewall of the dryer cabinet to serve as support for the three trays which could be slide also back and forth on them during loading and unloading. Each tray consists of 8 mm high wooden side wall and perforated bottom with aperture large enough to allow easy air movement and prevent the passage of cassava chips. Fan forced heated air is supplied to the dryer cabinet from the centrifugal fan/furnace/heat exchanger assembly through a pipe that connects to the perforated pipe network in the drying chamber. Although the furnace located below the heat exchanger could be fueled by either saw dust or charcoal, it was fueled by saw dust in this study(Taiwo,2009).

Methods

Two experiments were carried out in the study viz: Sun drying and drying with the cabinet dryer. Ten kilograms of fresh cassava tubers obtained from LAUTECH farm were weighed, washed, peeled, chipped and divided into two equal parts . One part was used for the sun drying experiment while the other part was used for the cabinet drying tests. Samples were taken from each of the two divided portions of the fresh cassava specimens and tested for total moisture content in accordance with ASAE standard S448.1.

Measured Parameters

Parameters measured include:

i. The size of the chips which is 2mm – 6mm by using the micrometer screw gauge.
ii. The quantity of fresh cassava chips using a weighing balance .
iii. The surface temperature of the Portland cement concrete paved drying floor and the temperature of the drying chamber of the cabinet dryer using the mercury thermometer.
iv. The elapsed drying time using a stop watch.
v. The relative humidity of the ambient air and that of the drying chamber of the cabinet dryer were determined using the wet and dry bulb thermometer in combination with the psychrometric chart .
vi. The ambient temperature of the dryer using a mercury bulb thermometer.

Moisture Content Calculation

The moisture content of the cassava chips on the wet mass basis were calculated in accordance with the following equations:

$$\%MWB = \frac{WM - DM}{WM} \times 100 \quad \text{........(1)}$$

Where:

%MWB = Percent moisture content, wet mass basis.

WM = Wet mass or mass of a given amount of cassava chips before drying, kg or g.

DM = Dry mass or mass of a given quantity of cassava chips after drying, kg or g.

WM – DM = Mass of moisture removed, kg or g.

Equation (1) was rearranged to allow for solving for DM and WM as follows:

$$DM = WM\left(1 - \frac{\%MWB}{100}\right) \quad \text{........(2)}$$

$$WM = \frac{DM}{1 - \frac{\%MWB}{100}} \quad \text{........(3)}$$

Moisture Content Measurement

Moisture dishes made of heavy gauge aluminium that does not dent easily were used. The dishes were provided with tightly fitting covers. Both the dish and its cover were identified by the same number. Before using the moisture dish was dried for one hour at the drying temperature to be used and the tare weight was obtained.

An airtight desiccator containing activated alumina for use as desiccant was utilized.

A minimum 100 g of representative portions of wet samples of chipped fresh cassava tubers were placed in each of three tared moisture dishes. The covered dishes and contents were weighed on an analytical balance to the nearest 0.01 g. The mass of each of the portions were determined by subtracting the mass of each dish from the total mass after which they were recorded. The dishes were uncovered and placed with their covers in the oven. The oven temperature was maintained at 105^{o}C while the dishes were weighed at two hour intervals until their masses were constant. The dishes were placed with the bulb of the oven thermometer kept as close to them as possible. At the end of the heating period, the dishes were covered as soon as possible and placed in the desiccator for them to cool to room temperature after which they were weighed. The percentage moisture content on wet basis was calculated by the use of Equation (1).

Evaluation of the Hourly Drying Floor Temperature and Moisture Content Variation during Sun Drying on Portland cement Concrete Paved Drying Floor

The evaluation of the hourly drying floor temperature and moisture content variation during sun drying on Portland cement concrete paved drying floor was carried out using the chipped peeled fresh Cassava. The fresh cassava tubers were peeled and cut into chips of lengths and widths which varied from 2mm – 4mm with a continuous flow rotary cassava chipper described in Taiwo (2012). A 4.5 kg portion was weighed and blanched with water at 70ºC. The purpose of the blanching was to deactivate the enzymes. The weighed blanched chips were spread in single layer on a carefully swept dry Portland cement concrete paved drying floor fenced with chicken wire at a height that will prevent the ingress of straying domestic animals. The cassava chips were left to dry in the sun for 10 hours while the hourly drying floor temperatures and mass of the drying chips were determined with the use of the measuring scale. The hourly mass of the drying cassava chips were used to determine their hourly moisture content on et basis with the use of Equations (1), (2) and (3). The hourly moisture contents on wet basis were plotted into a graph fitted with a least square line that gave the best R-squared value with the use of MICROSOFT statistical package. The package was further used to write the equation of the fitted curve and R-squared value on the chart.

Evaluation of the Cabinet Dryer

Evaluation of the mechanical-convection (forced-draft) type cassava chip cabinet batch dryer fueled with dry sawdust was carried out with another 4.5 kg portion of the chipped peeled fresh Cassava tubers used for sun drying evaluation. The chipped peeled fresh cassava tubers were further divided into three equal portions of 1.5 kg each and spread evenly in single layers on each of the 3 properly perforated trays in the cabinet dryer labeled trays 1, 2, and 3. Tray 1 is located at the lowest level in the dryer while tray 2 is in the middle with tray 3 next to the top. The clearance between tray 1 and the floor of the dryer cabinet was 14 cm while the overhead clearance between tray 1 and 2, 2 and 3 were 18 and 17 cm respectively. The overhead clearance between tray 3 and the roof of the dryer cabinet was 14 cm. the clearance between the trays and the two walls of the dryer cabinet was 8 cm. The 3 loaded trays were placed in the cabinet dryer when the temperature had stabilized after empty operation for a few minutes. At this time the temperatures of tray 1, 2 and 3 had stabilized at 40, 60 and 80^{o}C respectively.

The mass and percent moisture content on dry basis of the drying cassava chips on each of the 3 trays were determined in 30 minute intervals using the same method utilized for the sun drying experiment. They were tabulated and converted into charts which were fitted with regression lines with the best R-square values with the use of MICROSOFT statistical soft ware package. The equations of these lines and their R-squared values were displayed on the charts.

Results and Discussion

In order to compare the result of the cabinet dryer evaluation with what currently obtains on the field among cassava farmers and processors, the sun drying of cassava chips on concrete paved drying floor was evaluated. The results obtained were compared with those obtained from the tests carefully carried out on the dryer.

Evaluation of the Hourly Drying Floor Temperature and Moisture Content Variation during Sun Drying on Portland cement Concrete Paved Drying Floor

The observed data for the drying cassava chips spread in thin layer on the drying floor were plotted into graph of percentage moisture content on dry basis over a total elapsed time of 18 hours as shown in Figure 1. The initial moisture content of 71.47 % w.b. was gradually reduced to the final moisture content of 12.76 % w.b. The general trend of the data showed that a quadratic equation of the form $Y = aX^2 + bX + c$ could be fitted to predict the behaviour of the cassava chips subjected to sun drying under the natural conditions. The R-squared value of 0.9383 obtained showed that a computer program could be written to fit a polynomial equation of the second order and at the same time plot the observed and estimated data from the model. The curve of the estimated data was drawn and superimposed on the curve of the observed data in Figure 1 with the use of the MICROSOFT software package. The relation for a Portland cement concrete paved drying floor is given below:

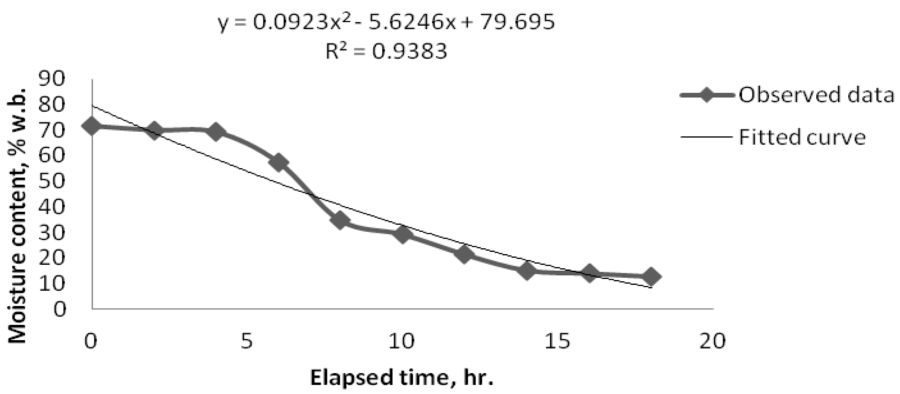

Figure 1. Observed and fitted moisture content trend line for sun drying(Floor temp. range, 40 - 65deg. Celsius.

$Y = 0.0923 X^2 – 5.6246 X + 79.695$ …..(4)

Where:

Y is the moisture content of the drying chips, % d. b.

X is the elapsed time, hours.

Equation (4) and the experimental data show that the moisture content of the drying cassava chips were 70.05 %, 57.57% and 13.99 % when the drying elapsed time were 2, 6 and 16 hours respectively.

Effect of elapsed time on drying rate

Results from the sun drying tests in Figure 1 shows that increase in Drying (or elapsed) time results in decrease in drying rate. This is due to the fact that as drying progresses the adhesive forces binding the water molecules and particles of the cassava chips together increases, thus more making it more difficult for the chips to lose their moisture content.

Evaluation of the Cabinet Dryer

The observed data for the drying cassava chips spread in thin layer on each of the three trays of the cabinet dryer drying floor were plotted into graph of percentage moisture content on dry basis over a total elapsed time of 3 hours as shown in Figures 2, 3 and 4. The dryer was tested with 1.5 kg of peeled fresh cassava chips with 2 – 4 mm average thickness for temperatures of 40, 60 and 80ºC on trays 1, 2 and 3 respectively at drying periods of 0.5, 1, 1.5, 2, 2.5, and 3 hours.

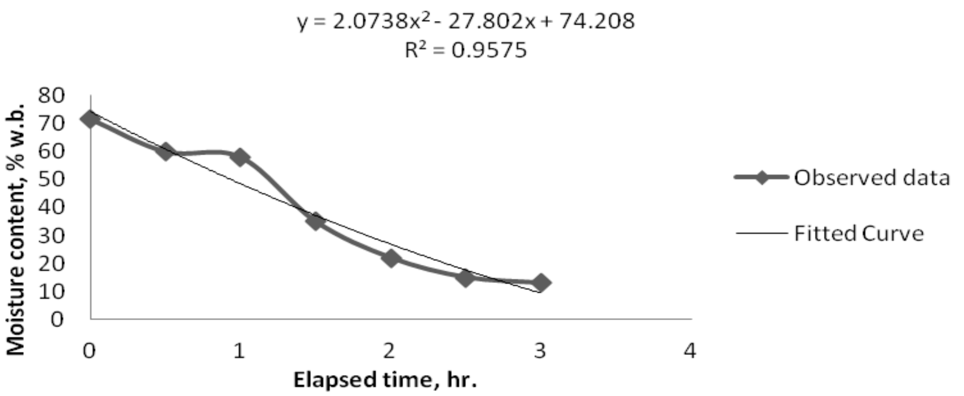

Figure 1.Observed and fitted moisture content trend line for Tray 1 (Temp. 40 deg. Celsius)

The test results show it took 3 hours to dry1.5 kg of cassava chips at 40ºC to a safe moisture content level of 13 % w.b. for storage when spread evenly in a single layer on tray 1(i.e. the bottom tray) of the cabinet dryer (Figure 1). Similarly, it took 3 hours to dry 1.5 kg of the cassava chips at 60^{o}C to safe moisture content level of 12 % w.b. for storage when spread evenly in a single layer on tray 2 (i.e. middle tray) of the cabinet dryer (Figure 3) while it took the same number of hours to dry the same mass of cassava chips at 80^{o}C to a safe moisture content of 11.5 % w.b. for storage when spread evenly in a single layer on tray 3 (Figure 4) .

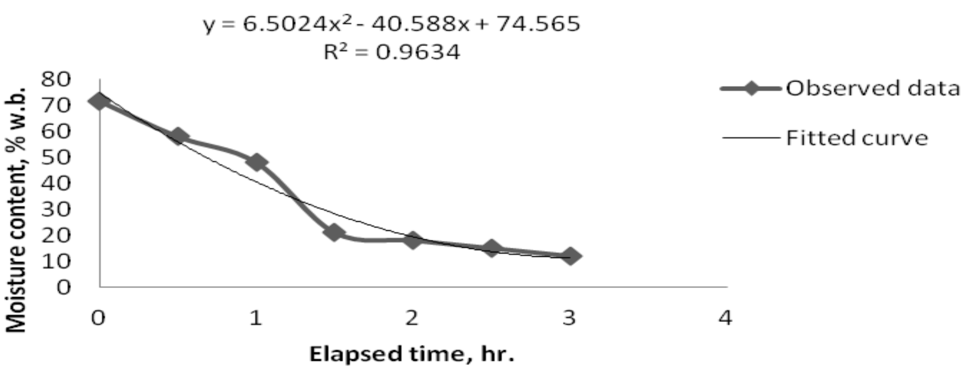

Figure 2. Observed and fitted moisture content trend line for Tray 2 (Temp., 60 deg Celsius)

This indicates that not only is less time spent in drying cassava chips with cabinet dryer than drying with the sun on fenced Portland cement concrete paved drying floor, less time is also spent in drying the chips on tray 3 of the dryer than time spent in drying on any other tray in the dryer.

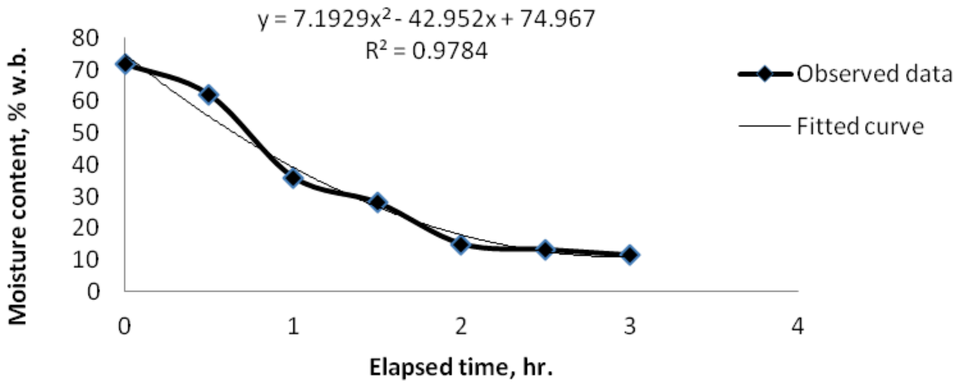

Figure 3.Observed and fitted moisturecontent trend line for Tray 3

Whenever cassava tubers are harvested in large quantities and drying is by sun drying on drying floors(as it is usually the case among most cassava farmers and processors) , rapid deteriorations often set in during the drying process because the chipped freshly-harvested roots usually contain high level of moisture which is left intact for a relatively long period of time while waiting to be dried to safe moisture content level. During this relatively long period of drying, the high concentration of some enzymes, such as linamarine, in it initiates some highly complex biochemical enzymatic activities which make the tubers deteriorate fast (Oke, 2005). This is, therefore, why the need for the introduction of faster drying devices to prevent the consequent economic losses can never be over emphasized. This, of course, has been the problem of so called peasant farmers and processors who constitute the bulk of cassava tuber and product producers in Nigeria and other cassava producing developing countries (Itodo, 1999; Taiwo, 2009). The introduction of the dryer evaluated in this work (which succeeded in drastically cutting down on the time required for drying by 83.3 %), into the cassava processing chain will go a long way in reducing the losses often incurred(usually due to quality of the dried product) during sun drying. The physical appearance of the cassava chips dried with the cabinet dyer in this study is an attestation to this fact. Not only were they observed to be whitish in colour in contrast to those sundried (which had cream colour), there was also no occurrence of case hardening. Instead they were found to be very brittle and crumbled easily when crushed. The whitish colour makes them attractive for use in both the pharmaceutical and confectionary industries and where they will attract premium price as opposed to the cream coloured chips which could only be used in only gari, fufu and animal feed manufacturing which will not attract as much price as those paid in the previously mentioned industries. The fact that the chips crumble easily is a physical condition which enhances easier and cheaper milling when viewed from the standpoint of energy required for the unit operation.

Overall, the performance of the cabinet dryer in terms of hours of drying and quality of dried product was much better than that of sun drying on cement concrete paved floor which is what most of our farmers and cassava processors currently use in drying their cassava chips.

Conclusions

The saw dust fueled cabinet dryer was evaluated by testing with 4.5 kg of fresh peeled cassava tuber chips. The collected data were analysed and compared with those obtained from tests carried out with the use sun drying technique. Regression equations were developed to relate percentage moisture contents of the drying cassava chips and elapsed (or drying) time for the two types of drying media. The statistical equations were also established to relate moisture content and hours of drying by the use of polynomial regression models of the second order (or quadratic regression models) which can be used for cassava chips drying on each of the three trays of the cabinet dryer as well as sun drying on Portland cement concrete paved drying floor.

While it took 16 hours to sundry 4.5 kg of the peeled cassava chips to a safe moisture content of 13.9 % w. b. during the humid raining season month of August, it took only 3 hours to bring 1.5 kg of the peeled fresh cassava chips to a safe moisture content of 13 % w.b. when placed on tray 1 of the cabinet dryer; it took 3 hours to bring 1.5 kg of the cassava chips to a safe moisture content of 12 % w. b. when placed on tray 2 and 3 hours to dry 1.5 kg to a safe moisture content of 11.5 % w.b. when placed on tray 3 of the cabinet dryer. Overall, it took 3 hours to dry 4.5 kg of the fresh peeled cassava chips to a safe average moisture content of 12.2 % w.b. when placed in the cabinet dryer during the same period of the year. This implies that there was a 15 hour (or 83.3 %) reduction in time required to dry 4.5 kg of the fresh peeled cassava chips to a safe moisture content when the cabinet dryer was used for the unit operation.

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