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EVALUATION of DESIGNED and DEVELOPED DETACHABLE NATURAL CONVECTION SOLAR DRYER for TOMATOES (*Solanum lycopersicum*) in KADUNA, NIGERIA

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ABSTRACT

This research work titled "Development of a Detachable Natural Convection Solar Dryer for Tomatoes (Solanum Lycopersicum) In Kaduna, Nigeria" was carried out to allow for drying of tomato, to reduce vegetable loss and to improve their quality. The dryer which is detachable basically consist of solar collector, drying chamber and chimney. Three different

Introduction

[1] reported that, [2] stated that drying involves the removal of moisture from agricultural produce. It is a simultaneous heat and mass transfer process. It involves two fundamental physical processes: the transfer of heat to evaporate moisture and the transfer of mass or moisture within and from the drying product. Drying can be done by sun drying; which has many demerits since it is totally dependent on good weather and very slow drying rate with danger of mould growth thereby causing deterioration and decomposition of the produce. The process also requires large area of land takes time and highly labour intensive [3].

varieties of tomatoes with two cuts orientations (traverse and longitudinal) of 100kg each to evaluate the dryer to obtained the drying rate. The data obtained were subjected to descriptive statistics; analysis of variance and drying rate curved of each of the variety were plotted. Beyond 5 hours of drying time, significant moisture removal was observed reaching a maximum value of 11.52kg/h at corresponding time of 8 hours for V1C1 and 10.32kg/h for V1C2 also within the same drying time. This means that an increase in moisture removal of 1.2kg was recorded between traverse cut and longitudinal cuts of Chivilli variety of tomato, also beyond 5 hours of drying time, significant moisture removal was observed reaching a maximum value of 10.26kg/h at corresponding time of 8 hours for V2C1 and 9.98kg/h for V2C2 also within the same drying time. This means that an increase in moisture removal of 0.28kg was recorded between traverse cut and longitudinal cuts of Grafto variety of tomato Beyond 5 hours of drying time, significant moisture removal was observed reaching a maximum value of 9.78kg/h at corresponding time of 8 hours for V1C1 and 11.38kg/h for V1C2 also within the same drying period. This means that an increase in moisture removal of 1.6kg was recorded between traverse cut and longitudinal cuts of UTC variety of tomato. The analysis of variance indicates that there is no significant difference in the mean values of the treatments.

Keywords: *Developed dryer, variety of tomatoes, cut orientation, drying time, moisture content*

In solar drying, solar dryers are specialized devices that control the drying process and protect agricultural product from damage by insect, dust and rain. In addition, it takes up less space, time and relatively inexpensive compared to artificial mechanical drying. The solar dryer can be seen as one of the solutions to the world's food and energy crises. With drying, most agricultural product can be preserved and this can be achieved more efficiently through the use of solar dryers [4] (Pravin *et al.*, 2017).

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Tomato fruit is one of the most popular, as well as important, commodities in the world. Over 20 million metric tons of tomato is produced each year on a world basis. The United States, Italy, Spain, and the United Arab Emirate are the leading producers of this crop. In the United States alone, it ranks second only to potatoes in production among vegetable crops and contributes approximately 400million dollars to the economy [5] (Weingberger and Lumpkin, 2007). Nigeria is ranked 2nd largest producer of tomato in Africa and 13th in the world with an estimated production of 1.701million/annum over a million hectares of land, with an average of 20-30 tons/hectare [6]. Despite the high figures in producing tomato in Nigeria, Nigeria imports over N 11 billion worth of processed tomatoes [7,6]. This is attributed to wastage at post harvest level. Tomatoes grown in the Northern part of Nigeria is transported to the Southern part of the country unprocessed, in baskets that fasten their deterioration due to its shape and the long distance. Several dryers have been designed and developed in rural areas where mass production of this fruit is done in Nigeria, generally these dryers have one or more of the limitations such as capacity, rigidity as well as cost if hygiene is to be improved.

However, drying characteristics of high moisture vegetables using this type of developed dryer system appears not to be available in the literature. Therefore, the main purpose of this study is to evaluate the performance of the developed dryer in terms of total drying time and final moisture content. In evaluating this dryer, tomato was used as experimental sample primarily because of its high moisture content of about 92% (wet basis).

Materials and Methods

A. Design workings

1. Mass of water to be evaporated

$$M_w = \frac{Mp(Mi-Mf)}{(100-Mf)} \quad ....1$$

Where M_w mass of evaporated water in (kg), M_p (kg) is the initial mass of product to be dried; ***Mi* (%) and *Mf* (%)** wet basis are the initial moisture content and the final moisture content, respectively. (Diemuodeke and Momoh, 2011)

2. Drying Rate

$d_r = \frac{Mw}{td}$ 2

where d_r is the drying rate, M_w mass of evaporated water,(kg) t_d drying time (hours) (Diemuodeke and Momoh, 2011).

3. Mass flow Rate

$m_a = \frac{dr}{\omega f - \omega i}$ 3

Where d_r is the drying rate, ω_f and ω_i (Psychrometric chart) are the final and initial humidity ratio, respectively (Diemuodeke and Momoh, 2011).

4. Volumetric flow rate

$Va = {ma}/{pa}$ 4

Where m_a is the mass flow rate in (kg/hr) and p_a is the density of air (Diemuodeke and Momoh, 2011).

5. **Total useful energy**

$Q_t = m_a*(h_f-h_i)*t_d$ 5

Where Q_t energy total energy required for drying (kJ or MJ), h_f ,= **98kJ/kg$_{da}$** h_i = **68kJ/kg$_{da}$** (Psychrometric chart) final and initial enthalpy respectively (kJ/kg$_{da}$), t_d time of drying (hours or seconds) (Diemuodeke and Momoh, 2011).

6. Area of collector

$A_c = Q_t \div (I_h * \eta * t_d)$ 6

Where Q_t energy total energy required for drying (kJ or MJ), I_h total global radiation on horizontal surfaces(kJ/m^2/day), η efficiency of the collector (ranges from 30-50%) t_d drying time(hours), (Diemuodeke and Momoh, 2011)

$A_c = L_cB_c$ 7

Note: B_c= length of dryer = length of vent

8. Area of vent

$A_v = \frac{Va}{ws}$ 8

Where, w_s = 1.55m/s wind speed (m/s) (Diemuodeke and Momoh, 2011).

$B_v = A_v/L_v$ 10

9. Base Insulator Thickness for the Collector

$Fm_aC_p(T_o - T_i) = KA_c(T_o - T_a)/t_b$......................................11

F, collector efficiency factor (10%), m_a mass flow rate (0.2328 kg/s), C_p specific heat capacity of air (1005 J/kgK) T_o,outlet temperature 60°C T_i, inlet temperature = T_a, ambient temperature (33°C), **K,** (0.087W/mK (Bali,2007)), A_c, area of collector (3.85m^2) t_b base insulator thickness (m).

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$t_b = KA_c(T_o - T_a)/ Fm_aC_p(T_o - T_i)$……………………….12

10. Outlet diameter

Length of vent (air inlet length) = air outlet length, but outlet is circular therefore, length of air inlet = circumference of the circular outlet.

$L_v = \pi D$, $D = L_v/\pi$ ……………………………………………13

11. Volume of drying chamber

$vol = lbh$ ……………………………………………………………14

Where, l is length of the dryer, b bredth of dryer, h, height of dryer from plenum

12. Height of dryer from the ground

To calculate the height of plenum to the ground, the solar collector makes a right angle with the plenum, adjacent angle is same as tilt angle of the solar collector,= 12°, the opposite angle calculated as 78° the length of the solar collector is the hypotenuse 2.48m, the length opposite to adjacent angle was calculated using trigonometry 2.426m

B. Performance Evaluation

1. Dryer efficiency

Drying efficiency is defined as the ratio of the energy required to evaporate the moisture inside the product to the energy supplied to the dryer. Total heat in this case of solar dryer is the available solar radiation upon the collector surface supplied to the dryer. The system drying efficiency will be calculated from

$\eta = (M_w * L_v)/(I_h * Ac * t_d)$ ----------------------------15

Where all parameters are the same as above (Lawrence *et al*., 2013)

2. Experimental Treatments and Design

Two cut orientation is considered transverse and longitudinal (T_1,T_2), while three varieties of tomatoes (V_1, V_2, and V_3) was used for the evaluation. Completely randomized design (CRD) in a 3x2 factorial experiment with three replications in each treatment was used.

Description of the Developed Dryer

The dryer consist of the following components of the frame support and serve as balance to the dryer. It was subjected to the direct weight or load of tomatoes to be dried, the solar collector, and the wind turbine ventilator rest on the main frame. Therefore, the material for the frame is of high rigidity, hardness, adequate toughness and posses' good machining characteristics. For this purpose, angle iron was used. The frames were constructed to allow easy assembling and disassembling the frames, and also attaching the drying trays.

The solar collector consists of angle iron as the frame and polythene sheet as the glazing material, which will produce greenhouse effect. Aluminium sheet was painted black to serve as the solar air heater. Well seasoned plywood was used from the outside to hold the aluminium sheet, the space between the aluminium sheet and plywood is insulated using saw dust material. For the collector to be fixed at an angle throughout the year without adjustment, the best tilt is to the latitude of Kaduna ($\beta = \phi = 10.6^{o}$) because of uniformity and having radiation gain in seven month [8](Bala, *et al.*, 2019). The collector assembly also consists of air flow channel enclosed by transparent cover and the absorber back plate provides effective air heating because solar radiation that passes through the transparent cover is then absorbed by both the mesh and black-plate. Air inlet vent is covered by a galvanized wire mesh to prevent entrance of rodents while the other end opens to the drying chamber.

The drying chambers consist of racks where trays are shelved; the trays were made of steel and wire gauze to allow penetration of heated air and evaporation of moist air. Air inlet and outlet were provided below and above the trays respectively. This facilitates the movement of air by natural convection. The four walls were made of 0.04mm pure Trampoline sheet, though not transparent but a good absorber of heat. This made the drying chamber not transparent and thus classified as mixed mode passive dryer. The top part of the chamber (roof) is inclined at angle 45^{o} at the diagonals, while the down part is made opaque made of aluminum sheet painted black with seasoned plywood serving as the insulation. The drying trays are made of mild steel and net to allow easy air circulation through the drying chamber. The flow of air is due to difference in vapour pressure within the drying chamber, and the escape of air through the chimney.

Fresh tomatoes were obtained from local markets in Kaduna, Nigeria. The tomato was sliced to approximate sizes of 1cm to increase the surface area exposed to drying air.

Plate 1: pictorial view of the developed detachable dryer

Drying Procedure

The experiment was performed in the month of April when the fabrications of the dryers were completed. Each experiment started at 7:00 am and continued till 6:00 pm for 13hrs. At the initial stage, digital thermometer was inserted in each of the dryers to monitor variation of temperature with time inside the drying cabinet. To determine moisture loss on the drying samples during experiments, 25 kg of the sliced tomato were weighed and neatly arranged in the drying cabinet with maximum of 25 kg per tray. Samples were taken out of the solar dryer and weighed at various time intervals, ranging from 30 minutes at the beginning of the drying process to 1hr during the last stage. The drying process was stopped when no further changes in the masses of drying tomato were observed. The mass of the tomato samples were determined with the help of a digital electronic weighing balance having an accuracy of 1% and the moisture content (wet basis) in each case was calculated using Equation (1).

$$Mw = (Mi - Mdt / Mi] \times 100 \quad (16)$$

Where: Mw is the moisture content in percentage; Mi is the initial weight of the tomato in kg and Mdt is the weight of the tomato at any time during the drying process in kg.[9] reported that the rate of drying at any given time in the dryer can be estimated using Equation (2). Similarly, both atmospheric and dryer temperatures were monitored and recorded at 30 minutes interval [9].

$$Rd = (Mp - Md)td \quad (17)$$

Where: Rd is the drying rate in kg/h; Mp is the weight of the tomato in kg; Md weight of the tomato at any given time in kg; td is the drying time (h) at which Md is obtained during the drying process. The total drying time is the difference between initial drying time and final drying time to achieve the equilibrium moisture content.

Result and Discussion

A *Drying Rate with Time*

The rate of moisture removal from the tomato as a function of drying time is shown in Figure 1, It is evident from Figure 1 that Chivilli variety (V1) cuts in traverse (C1) and in longitudinal (C2) at the initial stage of drying process (1-3 hours i.e 7am to 9am), the rate of moisture removal was insignificant in both cuts of the variety which corresponds to 3-5 hours i.e. 9.00-11.00am of the drying time. This was due to the low insulation and higher relative humidity during these periods. However, beyond 5 hours of drying time, significant moisture removal was observed reaching a maximum value of 11.52kg/h at corresponding time of 8 hours for V1C1 and 10.32kg/h for V1C2 also within the same drying time. This means that an increase in moisture removal of 1.2kg was recorded between traverse cut and longitudinal cuts of Chivilli variety of tomato.

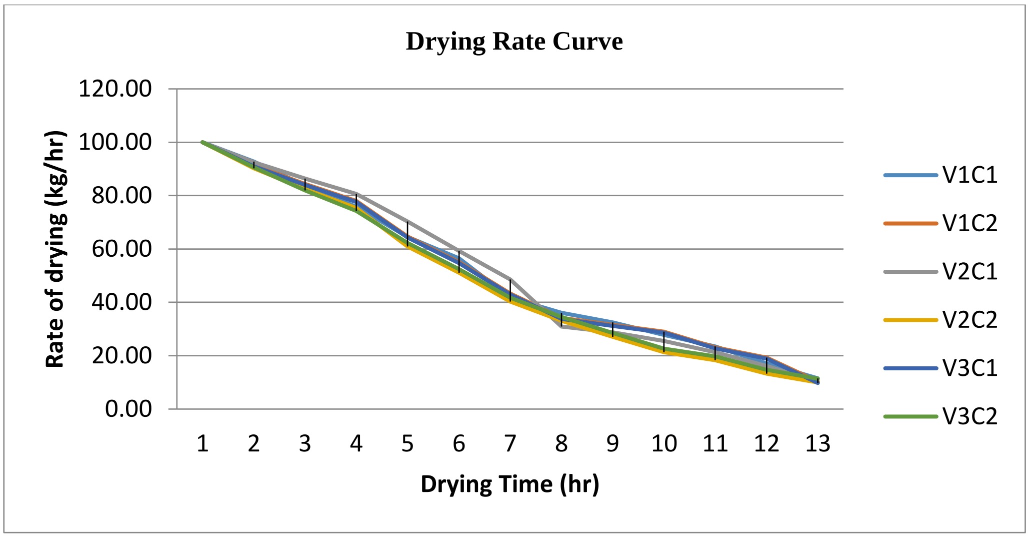

Fig 1 Drying Rate Curve

The rate of moisture removal from the tomato as a function of drying time is shown in Figure 1, It is evident from Figure 1 that at the initial stage of drying process (1-3 hours i.e 7am 10 9am), the rate of moisture removal was insignificant in both cuts of the variety which corresponds to 3-5 hours i.e. 9.00-11.00am of the drying time. This was due to the low insulation and higher relative humidity during these periods. However, beyond 5 hours of drying time, significant moisture removal was observed reaching a maximum value of 10.26kg/h at corresponding time of 8 hours for V2C1 and 9.98kg/h for V2C2 also within the same drying time. This means that an increase in moisture removal of 0.28kg was recorded between traverse cut and longitudinal cuts of Grafto variety of tomato.

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These higher drying times in both cuts orientations were attributed due to the attainment of peak insulation rate within the drying period and the moisture removed during these drying times were mostly free moisture or unbound moisture held within the porous structure of the tomato fiber and its removal is usually governed by mass transfer process [10].

CONCLUSION

Detachable Natural Convection Solar Dryer for Tomatoes (*Solanum Lycopersicum*) has successfully developed and evaluated. The temperature of the drying chamber remained higher than the ambient temperature throughout the experiment while the relative humidity remained high in the ambient temperature. The dryer can reduce significant moisture content of tomatoes from 95% to 14% within in less than 24hrs of drying time. Based on our drying experiment, drying of tomatoes can be achieved in less than 24hrs if the cuts dimension is less than 5mm and the weather condition is favorable.

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