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DEVELOPMENT OF A SOLAR DRYER FOR SMALL-SCALE FOOD PROCESSORS

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ABSTRACT: *Drying has been widely applied as a preservative measure for agricultural and food products. The common method of open sun-drying can pose a danger to the spread of deadly diseases, such as Lassa fever. This study, therefore presents an innovative design, construction and preliminary testing of a forced air convection solar dryer. The dryer consisted of a solar collector and the drying chamber. The dryer was constructed using locally available materials, and at the workshop, level cost 184, 810.00 Naira. Under no-load, maximum temperatures of 52.20^{0}C were recorded at the solar collector unit and 48.60^{0}C were obtained in the drying chamber, top of tray four. The dryer was used to dry blanched yam chips (10 mm thickness). Results revealed that the chips were dried from an initial moisture content of 70 % to 12% (wet basis) in 13 hours (two days of drying). Under loading conditions, the average maximum drying temperature obtained in the collector unit and the dryer cabinet were 54.71 and 47.03^{0}C, respectively. The results of the preliminary test suggest that the dryer has some drying potential, making it suitable for small-scale food processors.*

KEYWORDS: Solar Dryer, Yam Chip, Food Processing, Preliminary Testing.

INTRODUCTION

Drying is one of the agricultural processing operations that has been in existent for ages. It is one of the effective ways of food preservation from spoiling agents such as bacterial, mold, and insects. It is a process of reducing the moisture content of biological products to safe moisture thereby rendering the spoiling agents (Gupta *et al.*, 2017, Tandel *et al.*, 2017).

One of the simplest methods of carrying out drying is through sun drying. It is a natural way of drying by making use of renewable energy from the sun. It is the cheapest way of drying as it is affordable (because it free in supply) and requires little or no technicality in usage. This method of drying is predominant in the tropical regions, especially in Africa. In West African countries, sun drying is carried out through the spreading of agricultural products on mat lay on the floor, sometimes on the surface of flat rocks and even directly on the bare floor of the high ways.

This method of open sun drying, as cheap and affordable it seems to be, had a serious shortcoming in terms of human health due to unhygienic conditions that surround it. The spread of deadly diseases such as Lassa fever and tuberculous has been traced directly on indirectly to open sun drying by researchers (Mofolorunsho, 2016; Olayiwola1 and Bakarey, 2017; Woyessa *et al.*, 2019). Taking the case of Lassa fever as an example, the natural hosts for the virus are multimammate rats (Mastomysnatalenses). These rats feed on agricultural products during the drying process. The excreta of these rats have been reported as the primary means of transmitting the disease to humans.

The quality of the agricultural product obtained from open sun drying is as well impaired. Open-air drying comes with problems as the product is unprotected from rain, wind-borne dirt and dust, infestation by insects, rodents and other animals. The quality of products may be seriously lowered to the extent that sometimes becomes market valueless and inedible, with the attendant adverse economic effects on domestic and international markets (Alonge and Jackson, 2014).

Apart from open sun drying, agro-processors and food industries employ other methods in product drying. The commonly employed drying systems include cabinet dryers, flash dryers, solar cabinet dryers, rotary dryers and a combination of solar and indirect heating of the drying room, which can be described as a hybrid drying system. Most of the industrial dryers make use of electricity. The disadvantage of electrical/mechanical drying borders on the high cost and limited availability that can sustain the business of small-scale agro-processors.

This work aims to develop a solar dryer for small-scale agro-processors that safely protect the biomaterials from agents communicable diseases such as ebola, turbberculous and lassa fever. This is line with some of the objectives of Sustainable Development Goals (SDG) targets at providing a concrete framework for tackling poverty, hunger, maternal and child mortality, communicable disease, environmental damage and the global partnership for development.

MATERIALS AND METHODS

Design Considerations

In designing the solar dryer, the factors put into considerations include: The study area due to variation in weather. The weather conditions of Ado-Ekiti, Ekiti State Nigeria were used. The location of the end-user was considered to obtain maximum sun rays. The maximum angle of sun inclination of the study area was also consider to obtain maxium warn air for drying. The re-changing of the power source (DC battery) that powers the suction fan was also put into consideration hence, the solar panel was incorporated into this design.

Drying temperature was another factor considered in the design. The minimum and maximum drying temperatures for food is 35^0 C and 65^0 C respectively (Gupta *et al.*, 2017; Aburu*et al.*, 2018). Therefore, a minimum drying temperature of 40^0C was considered for this work. A rectangular the inverted frustum of the pyramid was used for proper hot air circulation.

The thickness of 4.5 mm was used in this work to meet glass covering of 4 to 5 mm thickness is recommended by literature. Also, an aluminum metal sheet of 0.9 mm thick was used to conform to 0.8 – 1.0 mm recommended. The air exhaust was provided for through suction fan of 12 V to remove the moist air from the drying chamber. A square perforated galvanized metal mesh was selected as drying trays to aid air circulation within the drying chamber.

Design Calculations

The sizes of the different components of the dryer were determined using standard formula and procedures.

Determination of tray size

In determining the size of the tray for the dryer, the average circumference of 50 yam tubers was measured and the relationship below was used to calculate the diameter of each tuber slide.

$$C=\pi D \quad \ldots\ldots(1)$$

Where C is Circumference of yam tuber slide (measured)

D is the average diameter of yam (cm)

Therefore, the surface area of each yam slide is calculated from

$$A = \frac{\pi D^2}{4} \quad \ldots\ldots(2)$$

It was assumed that the tray is a rectangular shape (Fig. 1)

Therefore, to get the length of the tray:

$$A_T = L \times B \quad \ldots\ldots(3)$$

Where L is Length of the tray (cm)

B is the Breadth of the tray (60cm assumed).

A_T is the total surface area occupied by 10 slices of yam.

Determination of the size of the drying chamber

The following assumptions were made in determining the size of the drying chamber

(i) The size depends on the number of drying trays to be housed. 4 trays were selected.

(ii) It was assumed that space between each tray be 15 cm (Fig.2)

(iii) The hanger to hold the tray was assumed to be 2 cm from the wall of the drying chamber (Fig.2)

Therefore, the size drying chamber was determined as:

$$H_{dc} = I_{n} + T \quad \ldots\ldots(4)$$

Where H_{dc} is Height of drying chamber (cm)

I_n is the inner height of the drying chamber

T is the Thickness of the drying chamber wall

Considering Fig. 3; the breadth of the drying chamber is determined as

B_{dc}=L_t+ T_d + T………………………………………………………..(5)

$Where\ L_t$ is Length of tray

T_d is the thickness of the door and T is the thickness of the drying chamber wall

Determination of the mass of moisture to be removed

To determine the mass of water to be removed from the product, the relationship used by (Al-Busoul,2017) was used as:

$M_w = \frac{Mp(mi-mf)}{(100-mf)}$ ……………………………………………… (6)

$where, m_p$ is the initial mass of the product to be dried (kg)

m_i is the initial moisture content ($\%w_b$)

m_f is the final desired moisture content ($\%w_b$) for safe storage.

The following factors were taken into consideration:

(i) The product: fresh yam tuber was selected

(ii) The initial mass is the mass of the product to be dried

(iii) The initial moisture content = 80%w_b(AbonoRorbet and Amoah 2015).

Determination of quality of heat needed to evaporate the water from the product

The quantity of heat needed is determined using an equation used by (Al – Busoul, 2017) as:

Q = $m_w \times h_{fg}$ ………………………………………………… (7)

Where Q is the amount of energy (heat) required for drying

m_w is the mass of water to be removed

h_{fg} is Latent heat of evaporation J/kg H_2O

The amount of heat needed as a function of temperature and moisture content of the product (Al – Busoul, 2017). The latent heat of vaporization is determined using equation (8) as used by (Al – Busoul, 2017) as:

h_{fg} = 4.186 × 10^3 (597 – 0.65 T_{pr}) ……………………………………(8)

Where, T_{pr} is product temperature is 40^0C (assumed)

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Determination of average drying rate (M_{dr})

Average drying rate, (M_{dr}) was determined from the mass of moisture content to be removed by solar heat and drying time using the equation given by (Al – Busoul, 2017) as:

$$m_{dr} = \frac{m_w}{t_d} \qquad (9)$$

Where, t_d is drying time

The drying time is taken to be an average sunshine hour in Ado – Ekiti (study area) and the mass of water to be removed (already calculated) was put into consideration.

Determination of area of solar collector

The area of the solar collector was determined by considering mass and volumetric flow rates of air. The mass flow rate of air ($\dot{m}_a$) was determined using the equation given by (Gupta *et al.*,2017) as:

$$\dot{m}_a = \dot{V}_a \rho_a \qquad (10)$$

Where $\dot{V}_a$ is the volumetric flow rate (m^3/s)

ρ_a is the density of air

But, $\dot{V}_a = V_a \times A_i$ ... (11)

Where, Va is the average air speed (Ado – Ekiti wind speed)

A_i isinlet surface area of the collector.

$$A_i = b_i \times h \qquad (12)$$

Where b is inlet breadth (previously calculated)

h = the air gap height

Substitute A_i in (11), $\dot{m}_a$ is calculated and the area of the solar collector is calculated using equation(13) as used by(Gupta *et al*.,2017).

$$A_c = \frac{\dot{m}_a C_{p \Delta T}}{b_c * I_c} \qquad (13)$$

Where, A_c is Area of solar collector

$\dot{m}_a$ isMass flow rate of air (previously calculated)

C_P is the specific heat capacity of the air

Δ_T is Change in temperature (room temperature and maximum temperature of drying food)

B_c isWidth of solar collector

I_c is Insulation on the solar collector surface

Insulation on the collector surface area (I_c) was determined by the equation given by (Gupta *et al.*,2017) as:

I_c= HR ……………………………………………………………… (14)

Where, H is Average solar daily radiation of the place (study area)

R is the average effective ratio of solar energy on tilted surface to that on the horizontal surface. = 1.017 (Gupta *et al.*,2017).

The length of solar collector (L_C)was determined as:

$L_C = \frac{A_C}{b_c}$…………………………………………………………….……. (15)

Where, A_C is the area of the solar collector (previously determined)

b_c is the breadth of the solar dryer (previously determined)

Determination of angle of tilt for solar collector

The angle of tilt of solar collector (β) was determined by the equation used by (Gupta *et al.*, 2017) as:

$\beta = 10^0 + \text{lat } \emptyset$…………………………………………………... (16)

Where, lat ∅ is the latitude of the study area.

Determination of the base insulator thickness for the solar collector

The rate of heat loss from the air is equal to the rate of heat conduction through the insulator. Using an energy balance equation as used by (Gupta *et al.*,2017) as:

$F\dot{m}_a \Delta T = \frac{KA_C \, \Delta T}{T_b}$……………………………………………………………………… (17)

Where, F is Factor of safety. (10% selected)

$\dot{m}_a$ is the mass flow rate, (previously calculated),

Δ_T is change intemperature between ambient and maximum drying temperature.

K is Thermal conductivity of /glass

A_C is the area of the solar collector (calculated previously) and T_b is insulator thickness.

Determination of total useful heat energy to evaporate moisture

The total useful heat energy required to evaporate moisture (received by drying air), kJ was calculated using equation (18) (Al – Busoul, 2017)

$E = M_a (h_f - h_i) t_d$……………………………………………………(18)

Where, E is total useful heat energy (kJ)

M_a is the mass of air kg

h_i and h_f is specific enthalpy at initial and final conditions respectively kJ/kg

t_d is drying time (6 hours for Study area)

Determination of air pressure

The pressure difference across the product bed will be only due to the density difference between the hot air inside the dryer and the ambient air. Air pressure was determined by the equation given by (Jindal and Gunasekaran, 1982) as:

$$P = 0.00308g\,(T_1 - T_{am})\,H \qquad (19)$$

Where, P is air pressure (Pa)

gis acceleration due to gravity

T_1 is final temperature

T_{am} is an ambient temperature

H is the pressure head (height of the hot air column from the base of the drying chamber to the top of air discharge)

Determination of fan size

In determining the size of fan needed to suck air from the solar collector and out of the drying chamber the mass of air to be transported, the distance to be covered and the time of operation were considered:

Therefore, work by the fan is given as:

$$W = F \times d \qquad (20)$$

Where F is force (N)

d is distance (m) from solar collector to the top of drying chamber

$$\text{But, } F = M_a g \qquad (21)$$

Where, M_a is mass of air (kg) (already calculated)

g is acceleration due to gravity hence, equation (20) becomes

$$W = M_a\, g\, d \qquad (22)$$

Power of the fan was calculated from

$$P = \frac{W}{t} \qquad (23)$$

Where, *t* is time of operation.

Materials Selection

The material was selected based on the available capital. The local materials were used for drying to reduce the cost. The fabrication was brought lower without lowering the machine efficiency so that local consumers can afford the machine at a lower price. Materials with high strength and rigidity were selected for the construction of dryer so that the machine can withstand compressive and shearing forces. The weight of the materials selected was considered so that the weight imposed on the tray will not be too much for the dryer.

Also, the materials selected were easily machine and worked upon, the materials with this property were selected so that the material can be fully maneuverer. The components selected were strong and durable, they are corrosion resistant and would be able to last longer to give the user the expected satisfaction with a profitable useful life span. It was ensured that there is minimum loss of heat through conduction hence poor heat conductor materials like plastic glass and wood were selected with proper lagging to prevent heat loss.

Construction Procedure

In constructing the solar dryer, each component of the dryer (drying chamber, drying tray, solar collector, frame) were constructed separately and then assembled to form a complete unit dryer as shown in Plate 1.

A white transparent plastic glass of 4mm thick was used for the construction of the drying chamber. It shaped in a frustum of a pyramid of four walls of 85 x 74cm. The dimensions were marked out on the full sheet of the plastic board (2440 x 1220mm) using a marker and the straight edge rule. This was cut- out using a plastic cutter.

The tray – hangers were constructed on the two sides wall by cutting 2cm strip of plastic material and gummed at 15cm adjacent height with adhesive gum (AB 4 minutes Eposy Steel Gum). This was followed by joining three sides wall edge to edge with the aid of aluminum angle iron cut to the height of the wall. The dimension of the drying chamber door (85cm x 75cm) was marked out and cut from the sheet of white transparent plastic glass. It was fitted through the hinge to one side of the drying chamber. The handle was made of the plastic glass of 2cm in the form of a rectangular shape and was fastened to the door.

Wire mesh was used for the construction of the tray of which 75cm by 65cm was cut out from the sheet of wire with the aid of pincher. Four trays were produced. The top of the drying chamber is a frustum of a pyramid. Every four sides of the frustum were cut out according to the size calculated and were joined together with the aid of aluminum angle iron. The solar collector was made of wood and aluminum sheet of 0.9 mm thick. The wood was cut out according to the calculated dimension and was joined together with aid of fastening screws. The aluminum sheet was nailed to the inner of the box and painted black to absorbed more heat. A plane glass of 1cm thickness was fixed on the top of the painted box for the concentration of heat. The solar collector box was placed on a four-legs stand constructed with angle iron.

Working Principle

The working principle of the dryer is based on the evaporation of moisture from biomaterial as a result of heat and mass transfer. The hot air produced from the solar collector is expected to move from higher concentration as a result of higher temperatures to the drying chamber. The hot air passes through the trays carrying moisture from the biomass to the outlet (exist) of the drying chamber which aided by a suction fan.

Testing Procedure

The dryer was set-up as shown in (Plate 1) in an open space during the sun-day. Thermometers were placed in the solar collector, and each of the four trays to measure the temperatures to study the condition of the drying system at the no-load situation. The temperature of the surrounding was also noted and recorded. Readings were taken and recorded every 30 minutes for two days for seven hours of sun per day.

In testing the dryer at loading condition; blanched yam was used as bio-mass material for the testing. The initial mass of the yam tuber was weighed and recorded. The yam was peeled and weighed, the peeled was also weighed. The yam was sliced to 10 mm thickness transversely.Hot water at a temperature of 80^0C was poured on the sliced peeled yam inside a bowland left for 24 hours of blanching.

The blanched yam was poured on a screen to drain the water for 30minutes and was carefully set on the solar dryer trays for drying. Temperatures from each of tray 1, 2, 3 and 4 (T_1, T_2, T_3 and T_4) and solar collector T_c were taken and recorded at interval of 30 minutes. The moisture content of the material was also determined on the daily basis for the periods of drying.The solar dryer is placed in an open place where it can assess full sun's radiation. Thesolar collector is set at an angle of tilt of the environment of 17.16^o. The sun rays fall on the solar collector, made of black painted wooden box with plane glass on top. As the glass gets heated,it heats the air within the box and heat move is transfer from higher concentration to lower concentration in the drying chamber. As the hot air passes through the perforated trays the material get dries by evaporation. The heat travels from the solar collector to tray1at the bottom to the uppermost tray4. The solar panel charges the battery, which powered the suction fan to suck away the moist air from the drying chamber.

Data Analysis

The data collected were analyzed statistically to evaluate the performance of the dryer through statistical tools (arithmetic mean, standard deviation and line graph) using Excel packages of window 7 of Microsoft words.

RESULTS AND DISCUSSION

The results of various components/parameters designed for are presented in Table 1 which was used for fabricating the system.It can be seen from the table that the drying chamber is 0.629 m^2. The dryer was designed to dry biomass at the rate of 1.3 kg/h; the heat of 18.76 kJ was designed for drying. The fabricated biomass solar dryer is shown in Plate 1. It consists of the solar panel, transparent plastic drying chamber, stands for drying chamber and solar collector.

The solar dryer was tested under two stages of no-loading and loading conditions. The average temperatures at the solar collector (T_c) , surrounding temperature (T_s) and at each (tray 1 (T_1), tray 2 (T_2), tray 3 (T_3) and tray 4 (T_4)) taken and recorded for two days at thirty minutesintervals for seven hours per day. The solar collector reaches its highest temperature of 52.20 ^{0}C at 150 minutes of commencement of the experiment. It was also noted that the temperature at solar collector fluctuates within the range of 35.20 and 52.20 ^{0}C this could be a result of variation in weather. One striking observation here is that despite the fluctuation in the air temperature at the solar collector, the temperature in the collector area was always higher than the temperature of the drying chamber and sorounding indicating that there build up heat in the collector. It is also safe to candidly state here that the minimum design temperature (40 ^{0}C) was exceeded at the collector area, while the maximum temperature in the drying chamber was 43.99 ^{0}C at tray T_4.

It can be inferred that at no–load, the dryer achieved its objective drying temperature of the minimum temperature of 40 ^{0}C for which it was designed. The dryer showed good results and has better potential if tested with different materials. This result is similar to the report of (Alonge and Jackson, 2014).

The Figures in 3, 4 and 5 give the curves pattern as well indicating a wide variation between T_c and T_1, T_2, T_3 and T_4 at day one of the drying. However, the drying chamber curves gets closer to that of the solar collector at day three and closest at day five. The implication is that by the time the material (blanched yam) which was initially wet form gets dried as the temperature at drying chamber is raised as a result of heat transfer from the solar collector.

It was noted that the drying day to bring the sliced yam to safe moisture content of 12 % was achieved within 13 hours (two) days of drying. This is seen to be a little faster than trdinaional open sun drying implying that the enclosure built up more heated air for drying.

CONCLUSION AND RECOMMENDATION

A simple solar dryer that can be used for agricultural produces processors was designed and constructed. The preliminary evaualtion shows that the dryer has potential of drying agricultural material. The temperature build up of 52 ^{0}C is within safe temperature for drying vegaetables to prevent vitamin loss. The dryer as well good for conservng the hygienic of foods form dealidy pandemic agents.

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APPENDIC

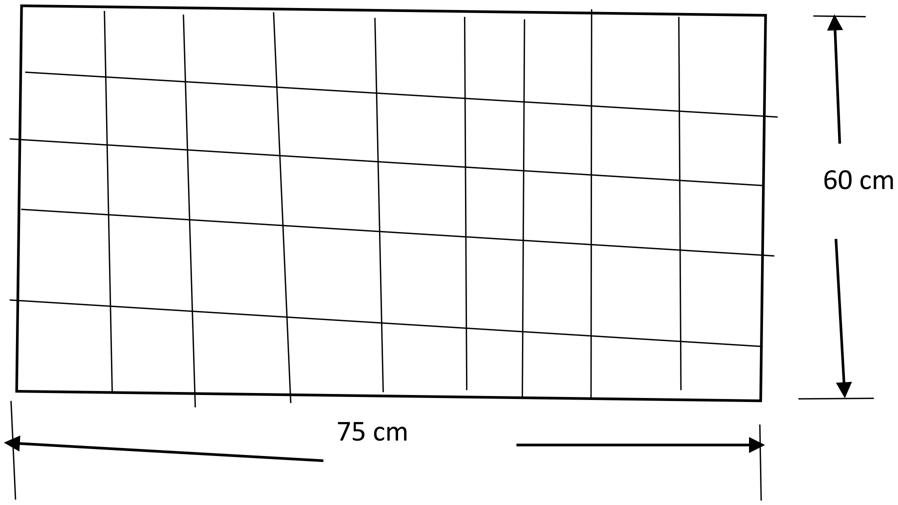

Fig. 1: Drying tray

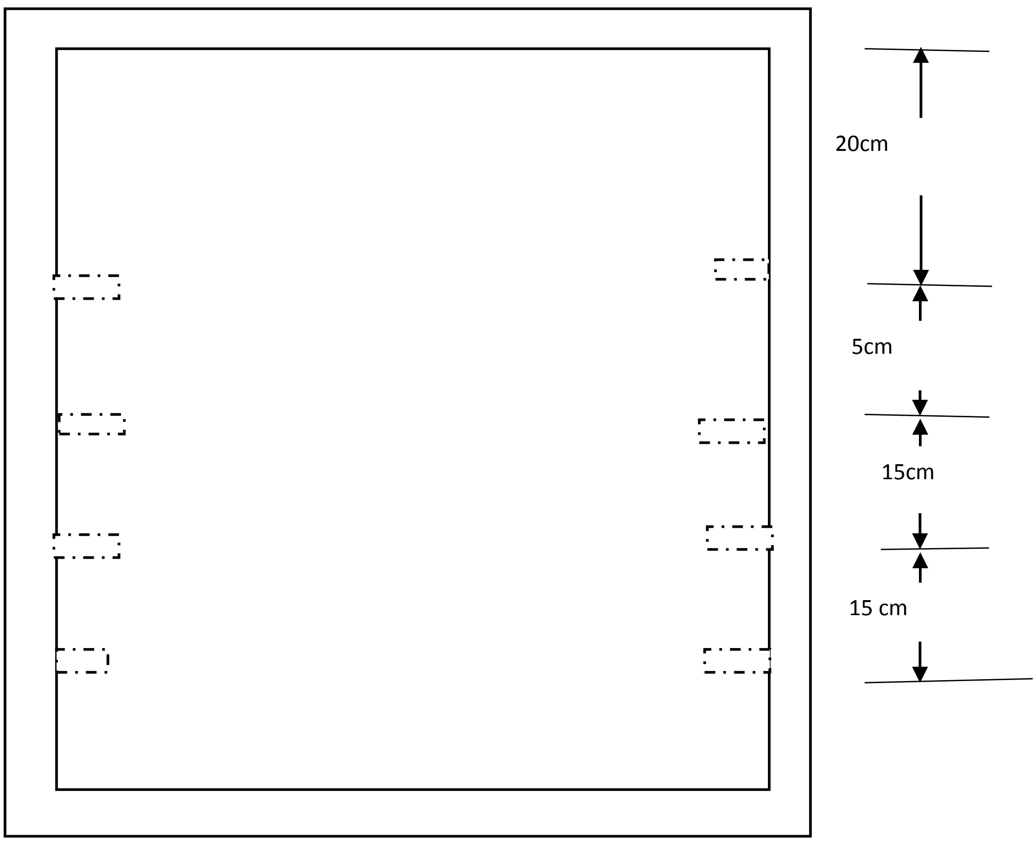

Fig 2: Front view of drying chamber

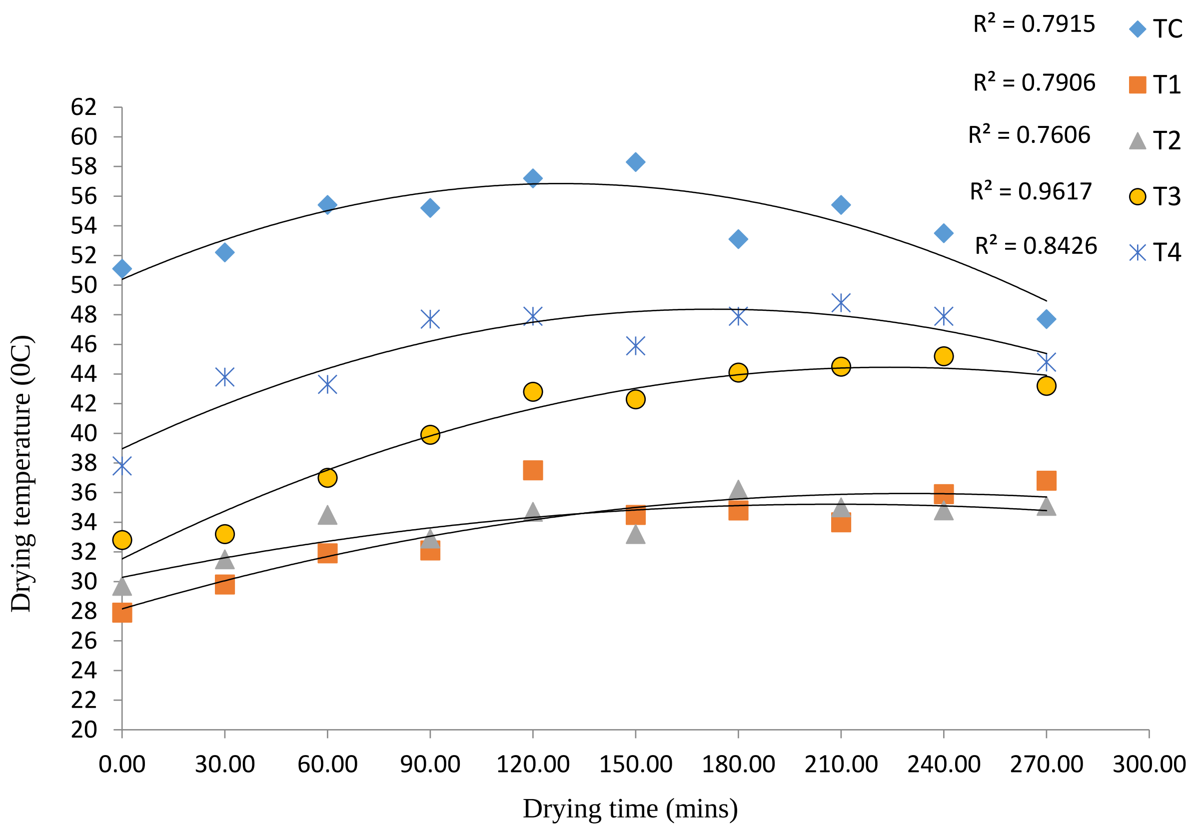

Fig. 3: The graph drying temperature (0C) at solar collector and each tray against time (mins) at day one

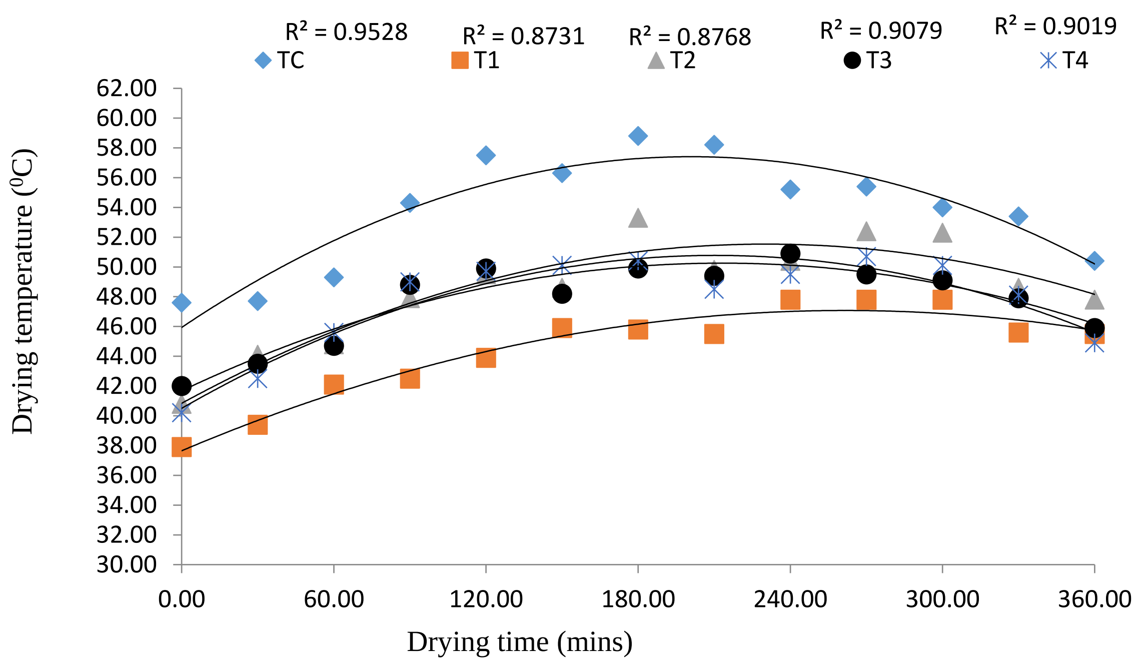

Fig. 4: The graph drying temperature (^{0}C) at solar collector and each tray against time (mins) at day three

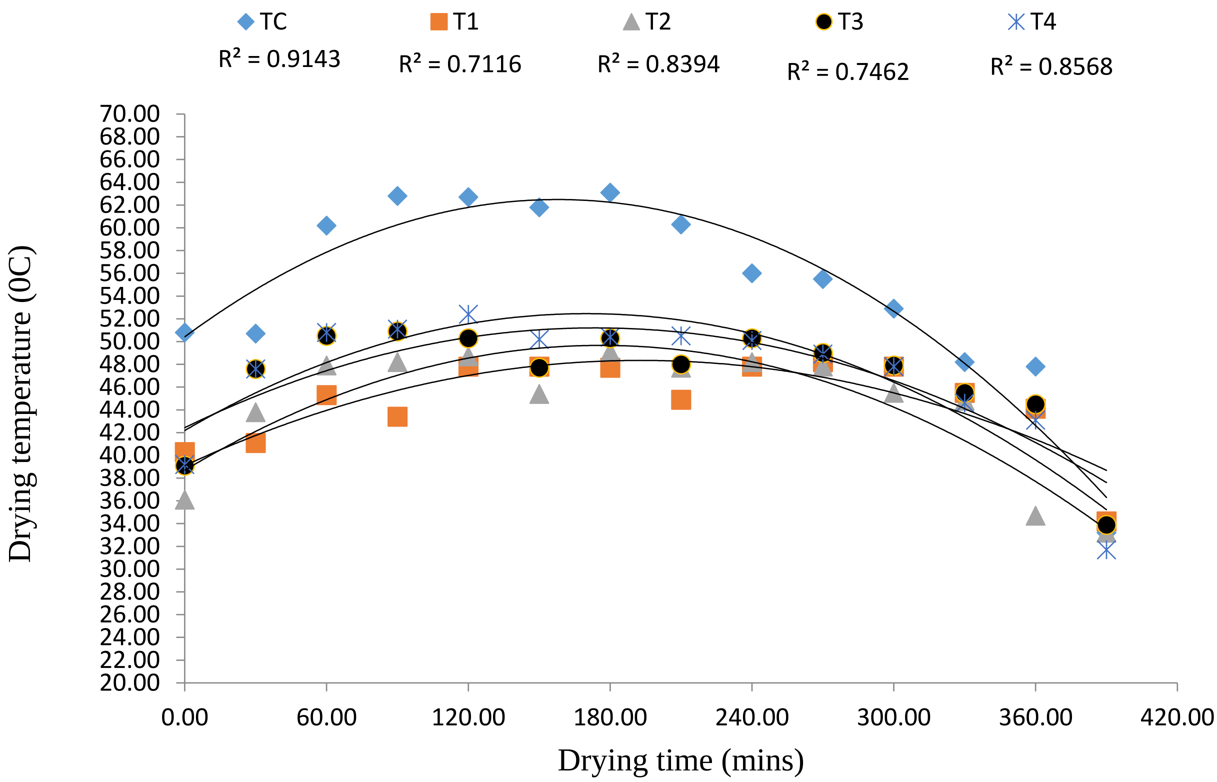

Fig. 5: The graph drying temperature (0C) at solar collector and each tray against time (mins) at day Five

Table 1: The values major parameters design

S/N	Parameter	Value parameter
1.	Area of drying chamber	0.629 m^2
2.	Quantity of moisture to be removed	7.8 kg
3.	Area of solar collector	39.279 m^2
4.	Mass flow rate	8.192×10^{-3} kg/s
5.	Drying Rate	1.3 kg/h
6.	Heat needed for drying	18.761 kJ
7.	Volumetric air flow rate	6.4×10^{-3} m^3/s
8.	Tilt Angle of solar collector	17.61^0
9.	Total useful heat energy to evaporate moisture	36,075 kJ
10.	Air pressure	1.20 Pa
11.	Fan power	0.0415 W

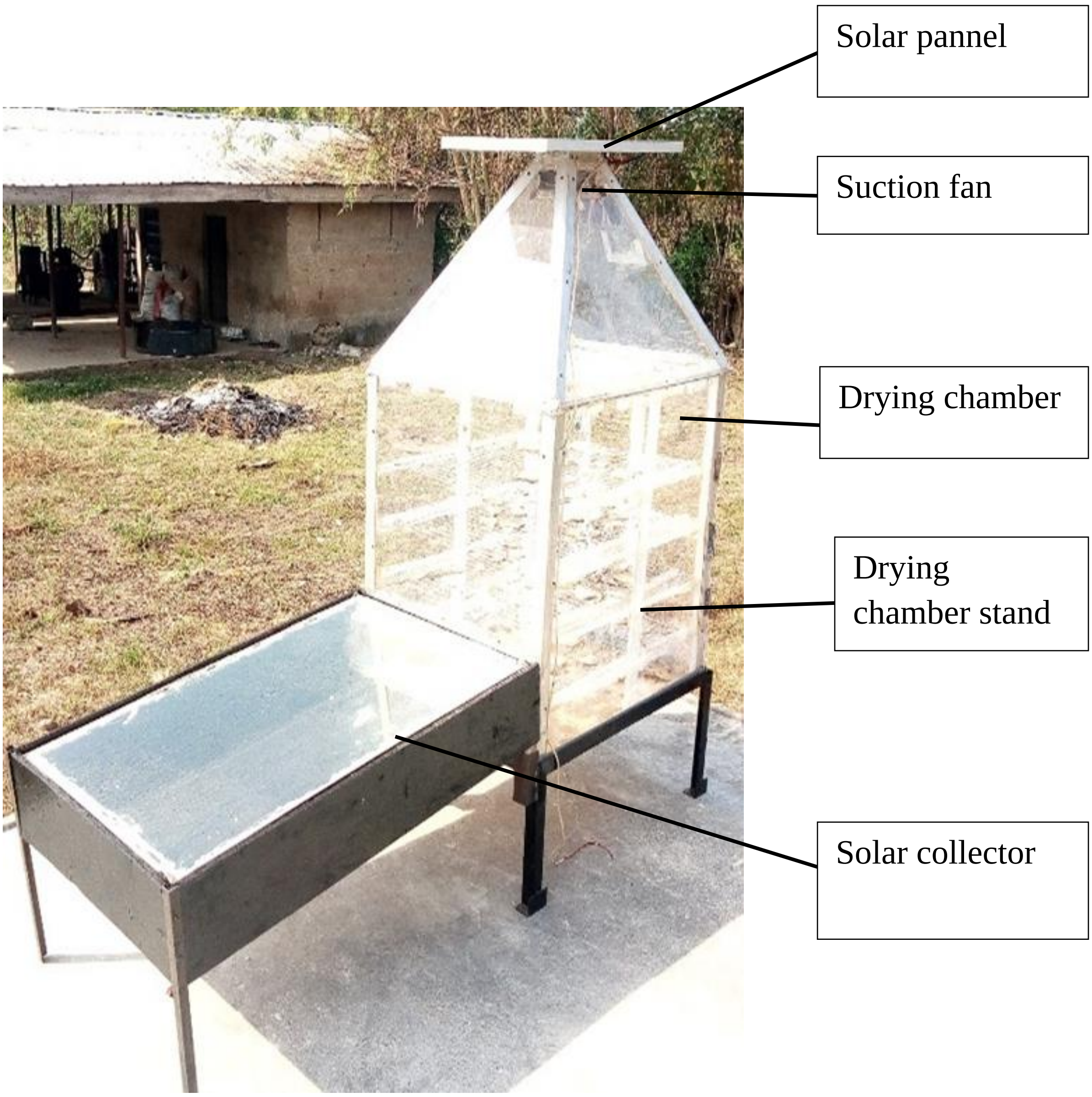

Fig 6: Solar Dryer for Small-Scale Food Processors