

Development of an Agro-Products Dryer Using Locally Sourced Materials

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ABSTRACT

The solar drying system utilizes solar energy to heat up air and dry any food substance loaded, which is not only beneficial in reducing wastage of agricultural produce but also helps in preservation of agricultural produce. Based on the limitations of the natural sun drying such as exposure to direct sunlight, likelihood of pests and rodents attacks, lack of proper monitoring and the escalated cost of the mechanical dryers; a solar dryer was therefore developed to cater for these limitations. Therefore, in this study, an indirect solar dryer composed of solar collector and a solar drying chamber with three compartments was developed and evaluated. The 3D modeling of the dryer was carried out using Pro/Engineer® software. After drying of cassava and yam chips for 300 minutes, average mass loss, drying rate and moisture content were determined as 35.5 g, 0.118 g/min, 59.41 % and 30.9 g, 0.103 g/min, 49.90 %, respectively. In addition, the cost analysis showed that the dryer was developed at ₦27,300.00, which is cheaper compared to those in the market as well as other dryers developed by other authors reported in literatures. The low cost of the dryer is attributed to the use of locally sourced materials.

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Introduction

Poor storage facilities and infrastructure are one of the leading causes of post-harvest losses in developing countries. In hot climates, fresh food and fruit products degrade or spoil due to lack of adequate storage facilities between harvest and market. Long life cycles and increased sales of perishable products necessitate the preservation of goods. Different methods of preservation are used to prevent goods from being damaged, lost, or decaying. In the case of perishable goods, it entails slowing or stopping microbial attack to extend shelf life. A method of preservation is any method used to keep food from spoiling. Space food preservation has become increasingly important in an age when fewer people eat foods grown on their own land and “out of season” foods are expected. Drying, freezing, refrigeration, curing, smoking, pickling, sugaring, canning, and bottling are some of the methods of food preservation [1]. One of the earliest methods of preservation is drying.

Drying is an excellent preservation technique for developing countries like Nigeria, that lack low-temperature and thermal processing infrastructure [2]. It is the process of removing moisture from products in order to slow down chemical reactions and kill pathogens that cause spoilage. Food is preserved by dehydrating foods to an acceptable percentage of moisture content because most microorganisms require moisture to thrive. It provides a way to preserve agricultural produce for food and sell, long after they have been harvested [3]. Heat and mass are transferred from products during drying and the surface moisture is first evaporated by the heat

source. The addition of some sort of energy forces further movement of inner moisture to the surface. According to Hedge *et al.* [5], drying is particularly beneficial in countries with limited low-temperature and thermal processing capabilities. Natural air drying, hot air drying, freeze drying, indirect or contact drying, and dielectric drying are all examples of drying methods.

Also, Akpojaro and Oyeyemi [5] revealed that due to growing concerns about the quality of the final product, the practice of open air drying or sun drying has become limited over time. As a result, solar drying systems have carved out a niche for themselves as a result of rising fuel prices, fossil fuel depletion, and the emergence of modern and efficient but not particularly cost-effective drying technologies. Amer *et al.* [6] described the design and performance of an indirect type solar fruit and vegetable dryer developed and the experimental results suggested that even under unfavourable weather conditions, the unit is capable to produce good quality products and low investment required.

Additionally, non-renewable energy sources are now used in majority of food processing and preservation activities in the industry. Shamiq *et al.* [7] revealed that the supply of energy is insufficient to meet the demand; as a result, alternatives to non-renewable and polluting fossil fuels must be investigated. One of the best solutions for reducing the use of non-renewable energy sources is to use renewable energy sources such as solar energy [7]. The sun generates energy through a series of thermo-nuclear reactions that produce a large amount of heat and electromagnetic radiation which

is widely distributed on the planet. Solar collectors, which are heat exchanger devices, trap this solar energy. In addition, most agricultural and food products have a moisture content of 70-80%. So far, food preservation has been controlled; however, these moisture values are extremely high, resulting in a reduction in product shelf life. Because of the moisture, the crops are frequently subjected to bacterial and fungal growth. These issues can be solved by using a solar dryer, which is completely pollution-free and produces no emissions or carbon particles [8]. Therefore, the objectives of this study are to develop a low cost solar dryer using locally sourced materials and evaluate the performance of the dryer using tuber chips.

Materials and Methods

The materials used in this study include, wood (agba) which serves as the casing or housing of the entire system. This material was selected as a result of its good insulating property as well as relative cost when compared to metals. A transparent glass was used to serve as the solar collector cover; the glass used in this work permit the solar radiation into the system and also resists the flow of heat energy out of the systems. In addition, a mild steel sheet of 1mm thickness and an aluminium roofing sheet which serves as a top cover of the developed system were also used. Other materials used in this work include; a wooden frame and galvanized wire gauze for constructing the trays, nails and adhesives, a net at air inlet and outlet-to prevent insects from entering into the dryer, hinges and handle for the dryer's door, wire, battery/power bank and a fan made with aluminum which is attached to a DC motor.

Design process and geometric modeling of the solar dryer

The design of the dryer involved the collection of the data such as temperature and humidity of study location (Jalingo). This process was followed by the geometric modeling of the solar dryer. In addition, in conceptualizing and design of the solar dryer, several factors were taken into consideration to ensure that the final product conforms to ideal conditions. Some of the factors considered include; available human resources, productivity, maintainability, drying efficiency, environmental conditions and cost effectiveness. Isometric projection and exploded view of the solar dryer are shown in Figs. 1 and 2, respectively.

Construction of the Solar Dryer

The solar dryer was constructed using plywood, galvanized steel mesh, wooden, transparent glass, galvanized mild steel sheet and axial fan for operation of the dryer, which are locally available at low cost. The thickness of yam and cassava slices was selected to be 2 mm. An indirect type of solar dryer was considered as it does not affect the colour and nutritional content of the produce as in the case

of direct type [9]. Flat plate collector was used since it can be easily worked on and also economical.

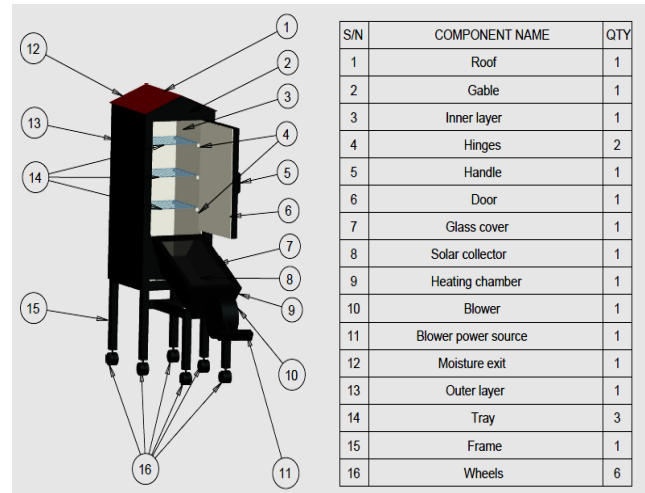


Fig. 1: Isometric projection of the solar dryer

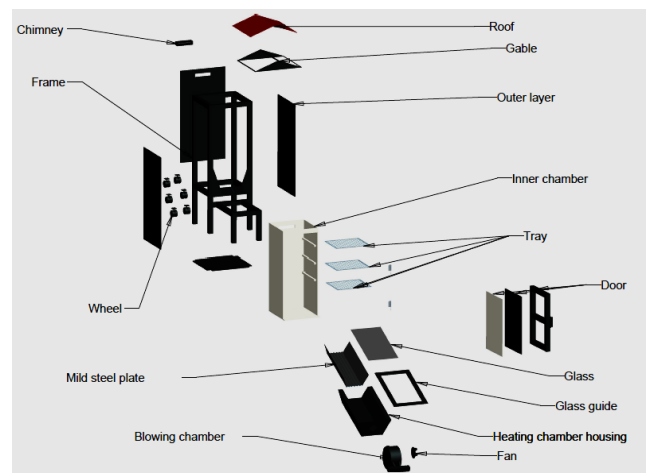


Fig. 2: Exploded view of the solar dryer

The collector was made up of mild steel of 0.5 mm thick as it is a good conductor and economical. It was thereafter painted black to increase the absorption of heat, as recommended by [10]. In addition, plywood was used as it is environmentally friendly, a good insulator and does not have any carcinogenic effects like other popular insulating materials such as glass wool.

Other construction process of the system involved the installation of food grade stainless steel mesh for the trays. This was installed to ensure constant flow rate of air during the experimentation process; also, an axial flow fan was installed. Production methods used include drilling, welding, cutting, planing,

thickening and fastening. The constructed solar dryer is shown in Fig. 3.



Fig. 3: Constructed solar dryer

Preparation of experimental samples

For the purpose of evaluating the performance of the solar dryer, cassava and yam chips were used. Specimens were prepared from the sourced yam and cassava tuber. Prepared specimens were washed and blanched in hot water for 3 minutes in order to avoid the discolouration of the samples during the experimental process. Thereafter, the specimens were weighed using a digital weighing balance of 0.1 g accuracy in order to determine the mass of each specimen. The prepared samples are shown in Fig. 4.



Fig. 4: Prepared experimental samples of cassava and yam chips

Performance evaluation of the solar dryer

The performance evaluation of the solar dryer involved placing the solar dryer outside the Faculty of Engineering building of Taraba State University, Jalingo. Preliminary preparation of the experimental process involved placing the prepared samples on each

tray of the solar dryer. Thereafter, a thermometer was placed on individual tray and the solar collector of the dryer in order to determine the temperatures at a specific time interval (1 hour). Afterward, the fan was put on using a battery and the door of the dryer was closed. The experiments were conducted from 11 am to 4 pm (5 hours) and the temperatures were measured for each hour from 11 am to 4 pm at three points on each tray, while the temperature of the collector was measured at the entry, middle and exit points. The average temperature readings were thereafter computed. Also, the final weights of the dried samples were measured using a digital weighing balance. All the experiments were repeated to confirm the repeatability of the data obtained. The drying rate (DR) and moisture content (MC) were calculated using Equations 1 and 2, respectively.

$$DR = \frac{M_i - M_d}{t} \quad (1)$$

where M_i = mass of sample before drying (g), M_d = mass of sample after drying (g), and t = drying period (min).

$$MC = \frac{W_w - W_d}{W_w} \times 100\% \quad (2)$$

where W_w = weight of wet material (g), and W_d = weight of dried material (g).

Cost analysis

The analysis of the cost of developing the solar dryer involves the preparation of cost data which plays an important role in ensuring that all the elements of production cost are considered. The factors taken into consideration during the construction and production of the solar dryer include; labour cost, cost of materials and indirect or overhead cost. In this work, the labour cost (LC) can be calculated using Equation 3. This involved cost of fabrication of metallic parts by the welder (FC), wage paid to carpenter (WC) and the cost of transportation (CT).

$$LC = FC + WC + CT \quad (3)$$

Cost of materials

Cost of material (MC) represent the raw materials from which the various components of the solar dryer were produced are shown in Table 1.

Table 1: Cost of materials

S/N	Materials	Qty	Size	Unit Price (₦)	Amount (₦)
1	Mild steel	1	1 × 500 × 300 mm	3000.00	3,000.00
2	fan	1		1200.00	1,200.00
3	Glass	1	4 × 1500 × 1800 mm	1000.00	1,000.00
4	Wheels	6		200.00	1200.00
5	Aluminium roofing sheet	1		500.00	500.00
6	Nails	1	Zig-zag, 1", 2", 2½ "and 3"		1,400.00
7	Paint	1		1,300.00	1,300.00
8	Tray	3		300.00	900.00
9	Wood			5,800.00	4,800.00
10	Battery	2		250.00	500.00
TOTAL					15,800.00

Table 2: Average temperature of each tray and collector

Tray	Time interval/Temperature				
	11-12pm	12-1pm	1-2pm	2-3pm	3-4pm
1	39.30°C	40.10 °C	36.60 °C	36.10°C	32.00 °C
2	37.50 °C	38.10°C	36.20 °C	35.80°C	30.10 °C
3	36.20 °C	36.70°C	35.80 °C	35.10°C	29.80 °C
Collector	49.90 °C	51.50	48.80 °C	42.30°C	34.0°C

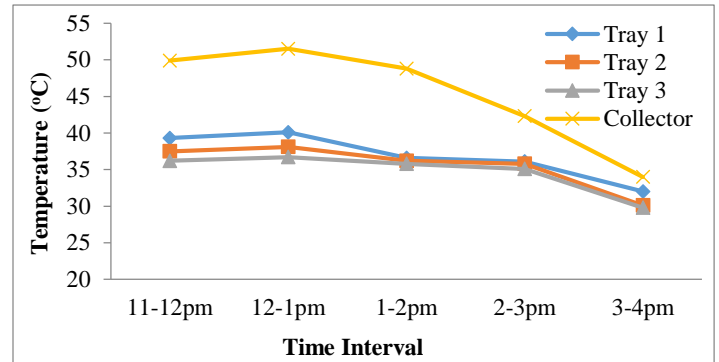


Fig. 5: Temperature reading for trays

Overhead cost

In the context of development of the solar dryer, overhead cost (OC) is assumed to be 30% of the material and labour costs. Therefore, the overhead cost can be calculated using Equation 4 while the cost of developing the solar dryer (CP) can be calculated using Equation 5.

$$OC = \frac{\text{Total Cost}}{100} \times 30 \tag{4}$$

where total cost = labour cost + material cost.

$$C.P = LC + MC + OC \tag{5}$$

where CP = cost of producing the solar dryer, LC = labour cost, MC = material cost and OC = overhead cost.

Results and Discussion

Thermal properties

Temperature readings taken at each tray is shown in Table 2 and represented in Fig. 5. The results presented in Fig. 5 revealed that more heat was generated at the collector compared to that of the tray. This was followed by Trays 1, 2 and 3. These results revealed that the dryer was constructed to standard and can be adopted for the drying of the agro-products.

Moisture content and drying rate

The results of the mass of the samples before and after drying for cassava and yam samples are presented in Tables 3 and 4, respectively. The results presented in Tables 3 and 4 are graphically presented in Fig. 6. Based on the results presented in Fig. 6, it can be observed that there was more mass loss of the cassava sample compared to the yam sample. Also, the moisture content and drying rate of the samples are presented in Table 5. Based on the results presented in Table 3 and 4, it can be seen that tray 1 has better drying rate and moisture content compared to other trays installed on the solar dryer. Average values of the mass loss, drying rate and moisture content for the cassava and yam chips are presented in Table 5.

Table 3: Mass loss of cassava samples

Parameter	Tray 1 (g)	Tray 2 (g)	Tray 3 (g)
Before drying	60.0	58	61.2
After drying	23.30	24.5	24.9
Mass loss	36.7	33.5	36.3

Table 4: Mass loss of yam samples

Parameter	Tray 1 (g)	Tray 2 (g)	Tray 3 (g)
Before drying	64.8	56.8	63.2
After drying	26.0	30.5	35.7
Mass loss	38.8	26.3	27.5

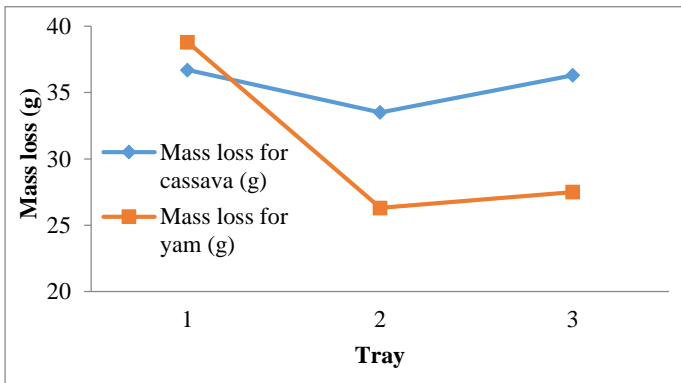


Fig. 6: Mass loss of samples

Table 5: Moisture content and drying rate of samples

Sample	Parameter	Tray 1 (g)	Tray 2 (g)	Tray 3 (g)	Average Values
Cassava	Mass loss	36.7	33.5	36.3	35.5
	Drying rate (g/min)	0.122	0.112	0.121	0.118
	Moisture content (%)	61.17	57.76	59.31	59.41
Yam	Mass loss	38.8	26.3	27.5	30.9
	Drying rate (g/min)	0.129	0.088	0.092	0.103
	Moisture content (%)	59.88	46.30	43.51	49.90

Cost analysis

Labour cost

Labour cost was calculated using Equation 3 and the results are shown in Table 6.

Table 6: Labour cost

S/N	Cost	Amount (₦)
1	Fabrication of metallic parts by the welder (FC)	2,500.00
2	Wage paid to carpenter (WC)	2,000.00
3	Cost of transportation (CT)	700.00
TOTAL		5,200.00

Overhead cost

The overhead cost was calculated using Equation 4

Material cost (MC) = ₦ 15,800.00, Labour cost (LC) = ₦5,200.00
 Total cost = ₦ 15,800.00 + ₦5,200.00 = ₦ 21,000.00

$$\text{Overhead cost (O.C)} = \frac{\text{₦ } 21,000}{100} \times 30 = \text{₦ } 6,300.00$$

Therefore, the cost of developing the solar dryer can be calculated using Eqn. 5

$$\text{C.P} = \text{₦ } 15,800.00 + \text{₦ } 5,200.00 + \text{₦ } 6,300.00 = \text{₦ } 27,300.00$$

Hence, the cost of developing the solar dryer was ₦ 27,300.00.

Conclusions

Solar energy has become increasingly popular in recent years. The main source of energy for solar drying is solar radiation. In this work, a solar dryer has been developed using locally available materials. The dryer was thereafter used to dry yam and cassava chips and the performance of the dryer was evaluated by drying for five hours, while the mass loss, drying rate and moisture content of the chips were calculated. Based on the results obtained from this work the following conclusions can be drawn.

- A low cost dryer was developed at a total cost of production of ₦ 27,300.00.
- Tray 1 recorded the best drying rate and moisture content compared to trays above it in the drying chamber.
- Drying rate of both cassava and yam chips was approximately 0.1 g/min.

Declaration of Interest Statement

The authors declare that they have no known competing financial interests or personal relationships that could have influenced the work reported in this paper.

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