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Performance Evaluation of a Prototype Solar Dryer against the Conventional Sun-drying System in Nigeria

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Authors' contributions

This work was carried out in collaboration between two authors JA and MO. Author JA designed the study, coordinated, supervised the work, managed literature searches and referencing, and wrote the final draft of the manuscript. Author MO participated in the design of the study, implemented the designed work, managed the analyses of the study, carried out literature searches, and participated in writing the first draft of the manuscript. Both authors have read and approved the final manuscript.

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ABSTRACT

Aims: The objective of this paper is to develop a rectangular solar dryer box in which grains are dried by direct radiation through the transparent walls and roof of the cabinet and by the heated air from the solar collector. The temperature development of the dryer is also evaluated.
Study Design: For the development of a rectangular solar dryer system and analysis of its performance against a conventional sun-drying system in the rural communities in Nigeria.
Place and Duration of Study: Department of Mathematical and Physical Sciences, College of Basic and Applied Sciences, Samuel Adegboyega University, Ogwa, Edo State, Nigeria; between July and December 2014.
Methodology: The dryer is made of wood with a box-like drying chamber with the top cover plate made of tempered glass of 5 mm. This is where the solar energy is trapped and channeled into the drying chamber. Air passing through the collector is heated. The collector consists of a glass cover plate, an absorber plate and insulator. A colorless glass of 5 mm thickness is used for the cover

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plate. It is 30 cm long and 15 cm wide. It traps heat from the sun and prevents it from escaping. It is placed 4 cm above the absorber plate, this collects solar radiation. The absorber plate is made of aluminum sheet painted black measuring 30 cm by 15 cm. It is placed below the cover plate to absorb incident solar radiation transmitted by the glass cover plate and heats the air passing between it and the cover plate.
Results: We evaluated the constructed solar dryer performance using 5kg of maize cobs. Savings in time were achieved as against open conventional sun drying, it took 2 days for the maize cobs to dry to a stabilized moisture content of 24.3 g from 30.3 g using the constructed passive solar dryer while it took 6 days to dry the same cobs to 25.4 g under the open conventional sun drying system.
Conclusion: The passive solar dryer dries grains faster than the open conventional system i.e. sunlight. Since the developed dryer does not use electricity, it can be used by farmers in rural communities. Physical observation showed that, the maize cobs in the dryer looked cleaner than those that were sun dried.

Keywords: Solar dryer box; moisture; clusters; ambient; humidity; prototype.

1. INTRODUCTION

In Nigeria, the use of solar system to dry and conserve agricultural produce such as coffee, vegetable, fruits, maize, beans, and other crops has not been fully utilized. However, the solar system of drying agricultural produce in many parts of the world has shown to be practical, economical and convenient environmental approach [1]. The use of solar heating system for drying food and other crops can improve the quality of the product. Drying and preservation of agricultural products have been one of the oldest uses of solar energy [2].

The traditional method, still widely used in developing countries, is open sun drying where diverse crops such as fruits, vegetable, and tobacco are spread on the ground and turned regularly until they are sufficiently dried. Traditional drying, which is frequently done on the ground in the open air is the most system used in Nigeria because it is the simplest and cheapest method of conserving foodstuffs [3]. Some of the disadvantages of this method are that it requires both large amount of space and long drying time, as well as exposing foodstuff to rain and dust.

The crop can be damaged because of uncontrolled drying and hostile weather conditions, infestation by insects and attack by animals. This could lead to slow drying rate, contamination and poor quality of dried products. However a better understanding of the method of utilizing solar energy has given rise to a scientific method called solar drying. However the availability of good information is lacking in many of the countries where solar food processing system is most needed [4]. The solar drying process depends on different parameters such as ambient air temperature, relative humidity, solar radiation and wind speed, amount on initial moisture content, type of dryer, etc. [5].

The determination of the drying efficiency of the solar drying process is very complex [6]. For instance, drying of banana in a solar cabinet takes three days for a better quality compared with that in the case of natural open sun drying. There are a large variety of solar dryers. They can be classified basically into two types: natural convection type dryers and forced circulation type dryers. Natural convection dryers do not require a fan to pump the air through the dryer. The low air flow rate and the long drying time, however, result in low drying capacity. Where large quantities of fresh produce are to be processed for commercial market, forced convection dryers should be used.

The aim of this study is to develop a rectangular solar dryer box in which grains are dried by direct radiation through the transparent walls and roof of the cabinet and by the heated air from the solar collector. The temperature development of the dryer is also evaluated. The technique of drying is probably the oldest method of food preservation practiced by mankind. The removal of moisture during drying prevents the growth and reproduction of microorganisms which cause decay and minimize many of the moisture deterioration reactions. Drying brings about substantial reduction in weight and volume thereby reducing packing, storage and transportation costs. It also enables the storability of the product under ambient temperatures [7]. The basic function of a dryer is to supply the product more heat than is available under ambient conditions, thereby increasing sufficiently the vapor pressure of the moisture held within the crop and decreasing significantly the relative humidity of the drying air and thus increasing its moisture carrying capacity and ensuring sufficiently low equilibrium moisture content [3].

The importance of solar drying is increasing worldwide, especially in areas where the use of the abundant, renewable and clean solar energy is essentially advantageous. The supply of solar energy is abundant in most locations in Nigeria where solar heat is intense virtually all the year round [3]. Maize *(Zea mays)* or corn is a very useful cereal crop in the world today. It is the world's most diverse crop species [8]. Maize has been the diet of many Nigerian families for centuries; it started as a subsistent crop and has gradually become a very important staple crop [7]. Maize has now risen from a mere subsistent crop to a commercial crop on which many agro-based industries depend on as raw material. Maize cultivation has spread widely in Nigeria due to the fact that farmers like its vigor and adaptation to wide spacing and intercropping system. The crop is fairly easy to weed and competes well with weeds because of its rapid vertical growth. Dry maize is relatively easy to transport and does not deteriorate rapidly while in storage. Consumers appreciate the low cost of maize and find it to be an appealing base for a wide array of local preparations.

Farmers in Nigeria face the problem of loss of their produce during post-harvest and storage. Freshly harvested maize with high moisture content is susceptible to rot and fungi infestation. Most farmers therefore accomplish their drying by thin layer spreading of their maize on disused roads, shoulders of tarred roads and hanging on wooden platforms. This simple method however allows the maize to be contaminated by dust, pebbles, stray animal droppings, insects, rodents and other animals [9]. The development of improved drying techniques are aimed at maintaining the maize in a clean, healthy, edible and storage condition and also ensure the availability of the maize all year round.

2. CONSTRUCTION OF THE SOLAR DRYER

2.1 Materials

The materials used in the construction of the solar dryer include;

- Log plank size 6 inches x10 ft.
- Two kilos of 2 inches of nail
- Hand spray knob
- Tempered glass of 5mm
- Thermo Cole insulator 30 cm by length
- Sand paper/plane
- Rubber bung
- Mercury in glass thermometer
- Hand saw
- Lathe machine (Brace)

The construction involves the following processes;

- Measurement and joining.
- Planning process.
- Alignment and painting.
- Coupling process.
- Temperature measurement.

2.2 Description of the Solar Dryer Box

The dryer is made of wood with a box-like drying chamber with the top cover plate made of tempered glass of 5 mm. The components of the Dryer include:

2.2.1 The solar collector

This is where the solar energy is trapped and channeled into the drying chamber. Air passing through the collector is heated. The collector consists of a glass cover plate, an absorber plate and insulator. A colorless glass of 5 mm thickness is used for the cover plate. It is 30 cm long and 15 cm wide. It traps energy from the sun by preventing it from escaping. It is placed 4 cm above the absorber plate, this collects solar radiation. The absorber plate is made of aluminum sheet painted black measuring 30 cm by 15 cm. It is placed below the cover plate to absorb incident solar radiation transmitted by the glass cover plate and heats the air passing between it and the cover plate.

2.2.2 The air passage

The gap between the cover plate and the absorber plate measures 10 cm, which forms the air passage.

2.2.3 The drying chamber

This is made of plywood with the outside coated with emulsion paint to avoid wetting and subsequent soaking of the wood when used during the rainy season. The plywood minimizes the heat lost by radiation. It has a door at the back where the drying layer is accessed. The drying layer is made of aluminum.

2.2.4 The outlet

This is an outlet for heated air to escape. It is made of aluminum sheet metal which is painted black. It is situated at the top of the dryer.

3. EVALUATION OF THE DRYER

In the drying process, moisture evaporates from the material being dried. The basic processes that take place include evaporation of moisture from the material to the surface and from the surface to the air [10]. The drying of a produce requires complex heat and mass transfer process which depends on external variables such as temperature, humidity and velocity of the air stream.

The evaluation of the dryer was centered on the moisture content reduction and temperature variations. The performance of the developed dryer was compared with conventional open sun drying, which is the popular method of drying employed by maize farmers in Nigeria. We used 5 kg of fresh maize cobs for the evaluation.

3.1 Temperature

Temperature was taken using a mercury-in-glass thermometer. Temperatures of the drying chamber, solar collector and ambient air were taken daily using thermometer on an hourly basis from 9:00 am to 5:00 pm for six days.

3.2 Estimation of the Dryer Efficiency

Moisture content (MC) was taken at the beginning and at the end of each drying day using the oven drying method and calculated using the model (1) below [11].

$$MC = \frac{Mi - Mf}{Mi} \times 100 \qquad \text{---------------} \qquad (1)$$

Where Mi is the mass of sample before drying and Mf mass of sample after drying.

The smoothed plywood (30 cm by 15 cm) in dimension is joined by one inch nails and glued together by an adhesive, neatly arranged as showed in Fig. 1. The box is carefully aligned with an absorber plate made up of aluminum sheet painted black, and placed below the cover plate. The solar dryer box is smoothened with the aid of planes, removing the rough edges, preparing its surface in readiness for the fixing of the cover plate (tempered glass). The absorber plate made of aluminum sheet of 30cm by 15cm is painted dull black in other to absorb maximum radiation energy and retained it.

Fig. 1. Prototype solar dryer box

The solar collector temperature was measured with the aid of liquid in glass thermometer and its variation with time was noted compared with the ambience temperature.

The box type solar collector system, with length 30 cm and width 15 cm, and height 45 cm as in Fig. 1, consists of absorber plate, single glass cover, back door and foam used as insulation. The system is framed with the single log. A single typical glass covered with thickness of 5 mm is placed in the top surface of the collector. Both side and bottom of the collector are insulated with 3 cm of foam. This minimizes the heat loss from inside of the box to surrounding of the box through both side wall and bottom wall. The solar dryer made by plywood material in the shape of rectangular length 30 cm, height 45cm and width 15 cm inside the solar dryer, between top glass cover and bottom heat absorber plate. A small hole of 3 cm diameter is provided on top of the dryer to remove the moisture content. The performance of the solar dryer box was evaluated by different climatic conditions during observation period to dry grains. Inside plate temperature and air temperature of the solar dryer incident solar radiation of the solar collector variation of moisture content of the grains and fruits during the observation period. The experiments started at 9:00 am and stopped at 5:00 pm during the observation period.

The solar dryer efficiency is calculated using the collection efficiency, ηc and system efficiency,

ηs . The collection efficiency measures the ratio of the useful energy output to the total radiation energy available during the same period and this is computed using the model (2).

$$\eta c = \frac{Qu}{Ac \times Is} \text{ -------------} \quad (2)$$

Where $Qu = m \times cp \times \Delta t$ (Qu is actual useful energy collected, m is mass flow rate of fluid, cp is heat capacity of fluid, and Δt is temperature change in the dryer). We used liquid (i.e., mercury) in glass thermometer to monitor the temperature. The measurement accuracy is calibrated to measure 0ºC to 100ºC. Ac is collector surface area, which can be interpreted as the transient value owing to the time dependence of the irradiance. Is is total solar radiation incident on the collector per area and time. With the time integral of utilized and input energy flow rates, we have;

$$\eta c = \int_0^t Qudt \text{ -------------} \quad (3)$$

$$Ac = \int_0^t Isdt \text{ --------------------} \quad (4)$$

The system drying efficiency is the ratio of the energy required to evaporate the moisture of the food material to the heat supplied to the drier. It is defined as;

$$\eta s = \frac{W \times L}{Is \times Ac} \text{ -------------------} \quad (5)$$

Where, W is the mass of moisture evaporated and L is the latent heat of evaporation of water at the dryer temperature. The dryer efficiency is computed as;

$$\eta d = \frac{\eta s}{\eta c} \text{ ------------------} \quad (6)$$

4. RESULTS AND DISCUSSION

Freshly harvested maize cobs with moisture content of 30.3 g were used for the evaluation of the solar dryer. From the obtained results, it took 2 days to dry the maize cobs to a stabilized moisture content of 24.3 g, while it took 6 days to sundry the maize cobs to 25.4 g moisture content. The dryer can be made in commercial sizes for rural community to fast track drying operations and quality of dried maize cobs. The result recorded from the variations of temperature with time from the solar dryer box before the drying process commences is shown (Table 2). The time in hours was taken with ambient temperature in degree, temperature of the collector and drying chamber were also recorded in degree. The results are computed using model (1) and presented as shown (Table 2) while Fig. 2 presents the graphical results.

The initial moisture content of the harvested fresh maize was 30.3 g. Variations in temperature was observed as shown (Table 1). Lower temperatures were recorded during the morning and evening hours with the morning hours recording the lowest temperatures. At 9:00 am, the ambient temperature was 30ºC, while the solar collector recorded 40ºC and the solar drying chamber had 35ºC. At 5:00 pm, the temperatures were 35.8^{o}C, 49.7ºC and 43.4ºC for ambient, solar collector and drying chambers respectively. It was observed from Fig. 2 that the temperatures in the solar collector were higher than the ambient temperatures. The solar collector recorded higher temperature at each reading than the ambient. The highest temperature was recorded during noon. At 1:00 pm, the ambient temperature was 38ºC while the solar collector recorded 59ºC and the solar drying chamber had 48ºC. Variations in moisture content were observed as shown (Table 2). The moisture content of the freshly harvested maize cobs was 30.3 g. At the end of drying for the first day at about 5:00 pm, the moisture content of the maize in the solar dryer reduced to 26.9 g while that of sun-drying reduced to 29.8 g.

From Fig. 3, on the second day, at about 9:00 am, the moisture content of the maize in the solar dryer is 26.6 g, which is safe moisture content for storage [12], while that of sun-drying reduced to 29.8 g. Sun drying eventually recorded 25.4 g at the end of the sixth day of drying. Generally, from Fig. 3, it was observed that drying occurred faster in the solar dryer than in the sun drying method. This is demonstrated by the consistent lowering of moisture content of the maize in the solar dryer, particularly in observations done at 5:00 pm. The moisture content of maize cobs in the developed dryer stabilized at 24.3 g at 5.00 pm on the second day.

The superior performance of the solar dryer was possible because temperatures in the drying chamber ranged from 36ºC to 48ºC while the ambient temperature ranged from 30ºC to 38ºC. There was also a little drop in moisture content at the interval between the end of each drying day and the beginning of the subsequent drying day. Furthermore, the maize cobs which were sun dried had to be taken into shelter at the end of each drying day to prevent dew from dropping on them. The quality of maize cobs in the solar drying chamber looked cleaner than the cobs which were sun-dried since they were placed in the drying chamber away from the effects of dust and dirt.

Table 1. Variations of temperature with time

Time (hours)	Ambient (ºC)	Collector (ºC)
9:00 am	30.0	40.0
10:00 am	33.7	42.2
11:00 am	35.5	47.9
12:00 noon	37.9	58.4
1:00 pm	38.0	59.0
2:00 pm	37.7	58.7
3:00 pm	36.4	56.4
4:00 pm	35.9	55.2
5:00 pm	33.8	49.7

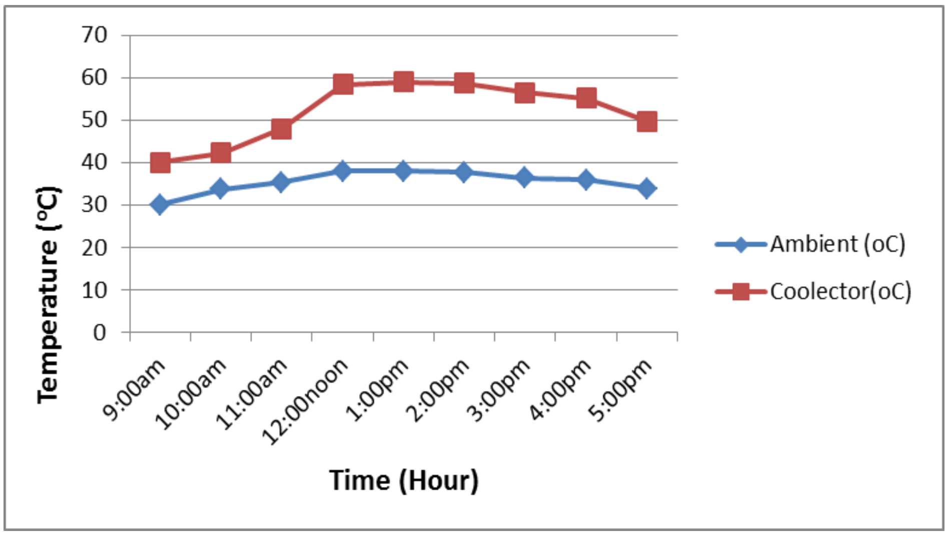

Fig. 2. The graph of temperature (ºC) against time (hour)

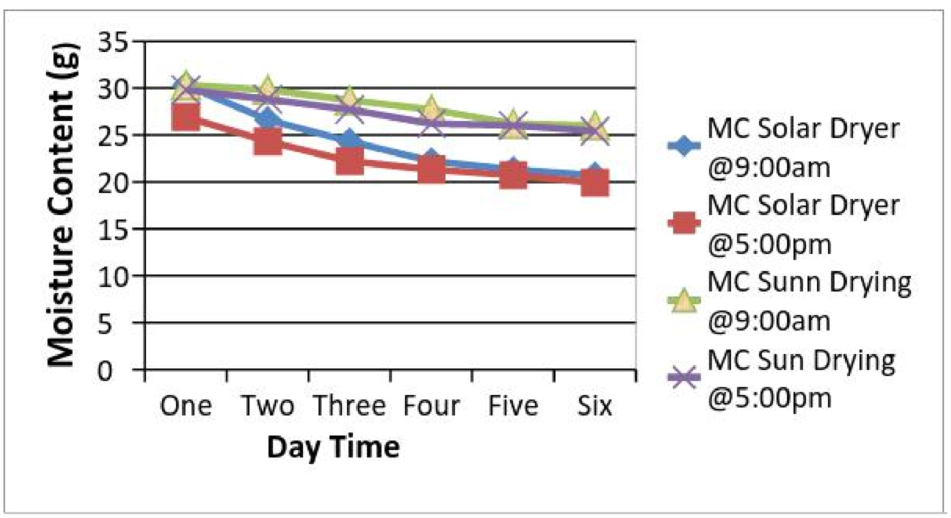

Fig. 3. The graph of moisture content against day time for period of drying (6 days)

Table 2. Variation of the moisture content with time for drying days

Moisture content (g)				
	Solar dryer box		Conventional sun drying	
Days	9:00 am	5:00 pm	9:00 am	5:00 pm
One	*30.3	26.9	*30.3	29.8
*Two	26.6	24.3	29.8	28.8
Three	24.3	22.2	28.7	27.7
Four	22.2	21.3	27.7	26.2
Five	21.3	20.7	26.2	26.0
Six	20.7	19.9	26.0	25.4

5. CONCLUSION

The performance of the prototype solar dryer box was evaluated using 5 kg of maize cobs. Savings in time were achieved as against the conventional open sun-drying system, it took 2 days to dry the maize cobs to a moisture content of 24.3 g from 30.3 g using the prototype solar dryer, while it took 6 days to dry the same quantity of maize cobs to 25.4 g under sun-drying scheme. Since the developed dryer does not use electricity, it can be used by farmers in rural communities in Nigeria. Physical observation showed that, the maize cobs in the dryer looked cleaner than those which were sun-dried. The performance of the dryer can be evaluated over a longer period of time of about three months to account for changes in weather to ascertain its maximum performance. In the future we are interested in doing this by scaling the solar dryer to accommodate commercial quantity of maize cobs.

COMPETING INTERSTS

Both authors have declared that no competing interests exist.

REFERENCES

1. Palaniappan, C. Perspectives of solar food processing in India. International Solar Food Processing Conference'09, India. 2009;1-11.
2. Idrisa YL, Shehu H, Ngamdu MB. Effects of adoption of improved maize seed on household food security in Gwoza Local Government Area of Borno State, Nigeria. Global Journal of Science Frontier Research Agriculture & Biology. 2012; 12(5):6-12.
3. Folaranmi J. Design, construction and testing of a simple solar food engine. African Journal of Food Science and Technology. 2008;48(2):95-101.
4. Ugbabe OO, Ahmed B, Manyong VM, Olukosi JO, Yusuf O. Economic analysis of balanced nutrient management technologies for maize production in Kaduna State, Nigeria. Journal of Applied Sciences. 2007;7(1):132-136.
5. Fagunwa AO, Koya OA, Faborode MO. Development of an intermittent solar dryer for cocoa beans. Agricultural Engineering International. 2009;9:1-14.
6. Oyekale AS, Idjesa E. Adoption of Improved maize seeds and production efficiency in rivers state, Nigeria. Academic Journal of Plant Sciences. 2009;2(1):44-50.
7. Ogunsumi LO, Olaniyi JO, Ewuola SO. Adoption pattern of farmers in Southwest, Nigeria: Thecase of maize and cassava farmers. Agriculture and Biology Journal of North America. 2010;1(4):476-481.
8. Ayinde OE, Adewumi MO, Olatunji GB, Babalola OA. Determinants of adoption of downy mildew resistant maize by small-scale farmers in Kwara State, Nigeria. Global Journal of Science Frontier Research. 2010;10(1):32-35.
9. Itodo IN. Evaluation of a solar crop dryer for rural application in Nigeria. Botswana Journal of Technology. 2002;11(2):58-62.
10. Ankit D, Asha D, Mai T. Analytical product design, mechanical engineering department, Michigan University; 2010.
11. Forson FK, Nazha A, Akuffo FO, Rajakaruna H. Design of mixed-mode natural convection solar crop dryers. Application of principles and rules of thumb. Renewable Energy. 2007;32.

12. Gallali. Preservation of Fruits and Vegetable using Solar Drier: A Comparative Study of Natural and Solar Drying III; Chemical Analysis and Sensory Evaluation data of the dried Samples (grapes, tomatoes and onions). Renewable Energy. 2000;19(1-2):203-212.

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