PERFORMANCE EVALUATION OF AN INDIRECT ACTIVE SOLAR DRYER FOR CROP PRODUCE (PLANTAIN)

Fasanu, Olugbenga
Department of Agricultural Education,
School of Vocational Education
Federal College of Education (Technical), Akoka, Lagos
fasanu2008@gmail.com / 07030755265

Okoh, Sunday Micheal
Department of Agricultural Education,
School of Vocational Education
Federal College of Education (Technical), Akoka, Lagos
mikesokoh74@gmail.com

Abstract

An Indirect Active Solar Dryer (IASD) was developed for drying crop produces using locally sourced materials. Experimental research design was adopted to evaluate the performance of the solar dryer. The (IASD) was equipped with sensors to measure and record key parameters such as temperature and relative humidity real time data throughout the experiment under zero and full loading conditions. Under full loading, freshly sliced plantain fillets were uniformly spread on trays inside the solar dryer and under open sun from 9am to 6pm. The weight of the fillets was measured before and after drying to determine moisture loss on hourly basis. The collected data were analyzed. During zero loading, the solar collector and the drying chamber recorded maximum temperatures of 68.5°C and 56.3°C respectively. For minimum relative humidity, the solar collector and the drying chamber recorded 22.6% and 35.2%. The solar collector attained an efficiency of 30.4%, with an absorbed energy of 0.63 kJ. Under loading conditions, the plantain fillets followed constant rate and falling rate drying pattern. On Day 1, the cumulative moisture removed by IASD was 1.46 kg (74.8% of initial content), compared to 0.96kg (49.1%) for Open Sun Drying (OSD). The IASD reached the equilibrium moisture content required for plantain storage (15%) within 18hours (2days), while OSD took 45hours (5days). This represents a 60% reduction in drying time with the IASD, highlighting its ability to quickly and efficiently reduce moisture content to safe storage levels. This rapid moisture removal highlights the dryer's capability to effectively reduce the moisture content of crop produces to a safe level for storage, ensuring their preservation. The study concludes that the IASD is an effective solution for drying crop produces for preservation, particularly in regions with abundant solar energy.

Keywords: Solar dryer, temperature, collector, efficiency, Plantain

Introduction

Post-harvest losses represent a critical challenge in the agricultural sector, particularly in developing countries where they can account for up to 40% of the total production of perishables such as fruits and vegetables (FAO, 2019). Plantain, a staple food in many African countries, is highly susceptible to spoilage due to its high moisture content and rapid ripening process. Traditional sun drying methods, commonly employed to extend the shelf life of plantain, are inefficient and unreliable, leading to significant losses and compromised quality of the dried produce (Afolabi & Agarry, 2014).

To address these challenges, solar drying technologies have been explored as a sustainable alternative to conventional drying methods. Solar dryers harness solar energy, offering an environmentally friendly, cost-effective solution for preserving agricultural produce. Among the various types of solar dryers, the indirect active solar dryer has gained attention for its ability to deliver controlled drying conditions while minimizing the risk of contamination and degradation of the often product (Simate, 2003).

An Indirect Active Solar Dryer operates by separating the drying chamber from the solar collector, allowing for the indirect transfer of heat to the crop. This design reduces the exposure of the produce to direct sunlight, which can lead to undesirable effects such as nutrient loss and discoloration (Madhlopa, Jones & Saka, 2002). Additionally, the active component, typically a fan, ensures forced convection of heated air through the drying chamber, promoting uniform drying and reducing drying time (Sharma, Chen, & Vu Lan, 2009).

Performance evaluation of solar dryers involves assessing key parameters such as drying efficiency, energy consumption, drying rate and drying time salvaged when compared to traditional drying methods. For plantain, maintaining the nutritional quality, color, and texture during the drying process is crucial, as these factors significantly impact consumer acceptance and market value (Akinola & Akinyemi, 2012). However, to obtain this, the drying must be carried out under optimal conditions. Studies have shown that the use of Indirect Active Solar dryers can enhance the drying process by reducing moisture content to safe levels this help preserve the quality attributes of the dried plantain (Oloruntoba *et al*., 2020).

Statement problem

The location of Nigeria on the globe made her to be endowed with favourable climate conditions that support the cultivation of varieties of both cash and food crops (Anonymous, 2022). It may therefore be expected that such a country with favourable climate, large arable land, and abundant agricultural produce should be listed among the countries that have attained a high level of food security. Unfortunately, the reality is that the attainment of security is still a mirage as a result of high levels of post-harvest losses (Arah *et al*., 2015). Since Nigeria is blessed with an abundant supply of sunshine hours and high solar radiation, the appropriate technology to adopt to overcome the challenges of open sun drying is the use of solar dryers.

Plantains, a staple crop in many tropical regions. They are highly perishable and require effective drying methods to extend their shelf life. However, the open sun drying method is prone to inconsistencies in drying rates due to fluctuating weather conditions, leading to uneven moisture removal and prolonged drying times. This inefficiency results in a higher risk of mold growth and other quality degradations. To address these challenges, an indirect active solar dryer offers a promising alternative. By utilizing controlled airflow and harnessing solar energy more efficiently, this technology aims to provide a more uniform and faster drying process. However, the performance and effectiveness of this technology in comparison to traditional methods require thorough evaluation, particularly in the drying of plantains.

This study seeks to evaluate the performance of an indirect active solar dryer (*IASD)* in drying plantains, comparing its efficiency, drying rate, and overall effectiveness against traditional open sun drying. The results of this evaluation will provide insights into the viability of adopting solar drying technologies for improved crop preservation.

Materials and methods

This study adopted an experimental research design to evaluate the performance of an Indirect Active Solar Dryer (IASD) developed for drying crop produces. The (IASD) was designed using locally available materials at the Federal College of Education (Technical), Akoka, Lagos in the Department of Agricultural Education Teaching/Research Laboratory. The material used are transparent glass, high quality marine board, aluminum sheets and other accessories

Construction of the dryer

The solar collector was constructed by combining 10 packed black coated corrugated aluminum sheets having each thickness of 0.4mm, 1500mm long and 600mm wide. The aluminum sheets form the heat absorber plate of the collector because it is a good heat conductor, readily available in the market, lightweight, cost effective and highly corrosion resistant. High Quality Marine Plywood insulation is provided to house the solar collector from both sides and bottom. The heat absorber plate is covered with a transparent glass having a thickness of 5mm to trap maximum solar radiation and to prevent heat loss to the environment by convection. The air entrance to the solar collector is screened with a double layer net in order to filter dusts, foreign materials and insects. The corrugations on the aluminum sheets were positioned across the air inlet path acted as baffles. They helped reduce air current speed, thus increasing the air contact time (drag) with the heat absorber plate. This design optimizes heat transfer, ensuring that the air mass reaches a high temperature quickly before entering the drying chamber. The solar collector is positioned to face the south and tilted at angle 17^{o} to the horizontal in order to maximize solar exposure.

The drying chamber is the place where dehydration of food to be dried takes place. It was designed to exhibit the shape of cuboids with the following dimension: 600mm wide, 600mm long and 900mm high. It was constructed using High Quality Marine Plywood. The plywood was used to prevent heat loss from the drying chamber to the surrounding. While the inner part of the drying chamber was lined with flat aluminum sheets in order to allow uniform heat distribution within the chamber. At the bottom of the drying chamber is 115mm diameter hole where the heated air is forced into the dryer. The Drying chamber can accommodate 3 trays with dimensions

570mm wide by 570mm long. Each tray can hold 1kg of fresh food material to be dried. The trays are made of wooden frame having aluminum mesh fitted to them.

A direct current brushless axial suction fan is fitted under a 105mm diameter hole bored at the closed end of the solar plate collector. The fan creates suction force on the heated air from the solar plate collector through the underneath 115mm diameter PVC pipe which exited into the bottom of the drying chamber. It is through this hole that heated air is forced into the drying chamber. The fan is powered by a pair of 12V, 7Ah battery charged by the solar panel through a 10Amperes digital charge controller. Elbow shape chimney with circular duct made from 76mm diameter PVC pipe accessory is provided directly at the top of the drying chamber, to remove the moisture laden air from the solar dryer. The specification summary of the dryer is highlighted in Table 1 below. The schematic diagram is show in figure 1

Table 1. Summary of the Specifications of the Solar Dryer

Descriptions	**Unit**	**Value**
Volume of the of drying chamber	m^3	0.216
Thickness of the solar collector glass	mm	5
Total thickness of the aluminum absorber plate	mm	5
Surface area of the solar collector	m^2	0.9
Depth of the collector air vent	mm	90
Surface area of each tray	m^2	0.36
Loading capacity of the dryer	kg	3
Tilt angle of the collector	Degree	17.5
Power of the fan	Watt	7.2
Solar panel Power rating	Watt	80
Total Battery rating	Watt	168

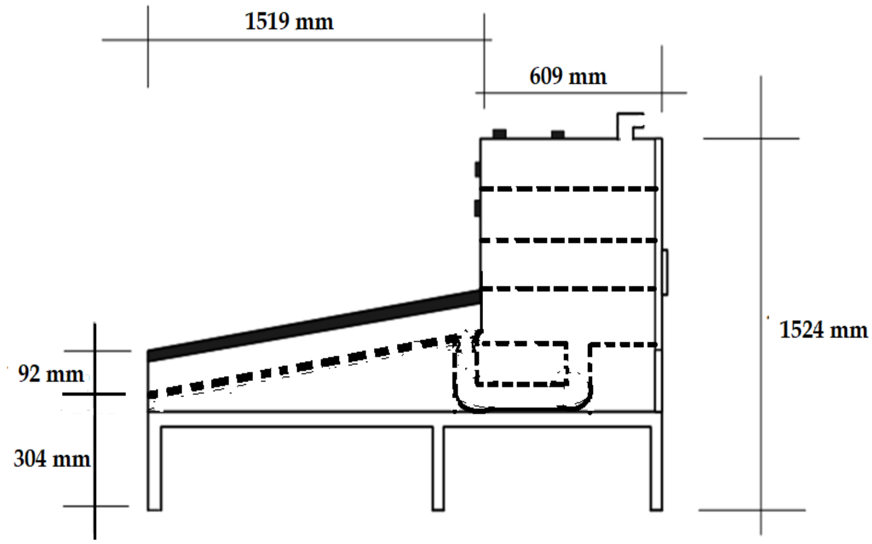

Figure 1 The Schematic diagram of the dryer

Experimental procedure

The dryer was conveyed to location where it can receive direct sunlight without interception within the College. The thermal performance test was carried out shortly after the dryer was constructed in the month of March. Several zero load (Nothing was placed in the drying chamber of the dryer) tests were carried out for 15 consecutive days. The test was carried out from 9am to 6pm daily. The ambient air condition was determined through the digital sensors (temperature and relative humidity) and the readings from the digital solar charge controller. The air condition within the solar collector, and the drying chamber were determined through the readings of the digital temperature and humidity sensors placed at these points. Temperature at the chimney was measured using the infrared thermometer. Digital anemometer was used to measure the airflow inside the solar collector and within the drying chamber. The readings were taken on 30minutes basis.

Thereafter, the dryer was loaded with freshly sliced plantain. The sliced plantains were arranged in three trays. Prior to the loading of the trays, each tray was weighed empty and their weights were recorded. Thereafter, known weights of the fresh sliced plantain (3.0kg) were arranged inside the trays to permit easy circulation of air for moisture removal uniformity within the drying chamber and conveyance of moisture laden air out of the dryer. The tray and its contents were then loaded into the dryer at equal spacing. The door of the dryer was shut. At interval of every one hour, the tray alongside the sliced plantain was weighed. The weights were recorded. Data on the drying time, weight reduction, air flow speed, temperature and relative humidity were recorded every 30 min and later converted to hourly readings. In order to determine the percentage drying time salvaged by the dryer, the same weight of plantain to be loaded into the dryer was replicated and placed under open sun drying. The drying rate was also monitored.

Figure 2:Solar dryer during the experiment

Figure 3; Dried plantain during the performance evaluation of the dryer

Performance evaluation parameters

The performance of solar dryer system was determined using the following; Absorbed energy, Solar collector efficiency, drying rate and percentage drying time salvaged.

Absorbed energy

This is the heat energy used to raise the temperature of the air passing through the solar collector from the environment (ambient) before moving into the drying chamber.

$$Q = M_a\ C_p\ (T_f - T_a) \qquad \text{-------------} \ (i)$$

M_a is the mass flow rate of the air stream through the solar collector. C_p is the specific heat capacity of air (1.095 kJkg^{-1}K^{-1}). T_a is the ambient temperature, T_f is the temperature of outgoing air from the collector

Solar collector efficiency

This is the effectiveness of a solar collector in converting solar radiation into usable thermal energy. It is a measure of how efficiently the collector captures and utilizes the solar energy that falls upon it.

$$\eta_\mathrm{c} = \frac{M_a C_p (T_f - T_a)}{A_c\ H} \qquad \text{----------------} (ii)$$

M_a is the mass flow rate of the air stream through the solar collector. C_p is the specific heat capacity of air (1.095kJkg^{-1}K^{-1}). A_c is the collector surface area (m^2), T_a is the ambient temperature, T_f is the temperature of outgoing air from the collector and H is the total irradiance *(kWh/m^2/day)*

Drying rate

The drying rate is expressed as the derivative of the moisture content (M) with respect to time (t). Mathematically, the drying rate (DR) can be represented by the following differential equation:

$$DR = \frac{dM}{dt} \text{ -----------------(iii)}$$

Where: DR = Drying rate (kg/hr)

M = Moisture content of the plantain (kg)

t = Drying time (hr)

Percentage drying time salvaged

The time saved by using a solar dryer compared to the traditional open sun drying (OSD) method expressed in percentage using:

$$\text{Percentage Drying Time Salvaged} = \frac{T_{OS} - T_{SD}}{T_{OS}} \times 100 \text{------------(iv)}$$

T_{OS} = Drying time to reach safe moisture level for optimum storage using the open sun drying method

T_{SD} = Drying time to reach safe moisture level for optimum storage using the solar dryer

Data analysis

Data collected were analyzed using the spreadsheets, trends in temperature and humidity were plotted, and correlations between drying conditions and performance parameters were explored.

Results and discussions

Air temperature and relative humidity trends

The solar dryer temperature and relative humidity profile obtained under zero loading condition are shown in Figure 4 and 5. The operation time of the day commences from 9am to 6pm. The average ambient, solar collector and drying chamber temperatures started at the same point 30.7°C at 9am. This indicated that the air in the dryer's environment was at the same microclimate. Gradual increase was observed for all the temperatures. The temperatures rise sharply from 9 am to 1 pm, reflecting the increasing intensity of solar radiation. In the tropics, the highest temperature during the day occurs at solar noon or a few hours after, which can be between 12pm to 2pm, depending on the specific location and time of year. At this time intervals, the solar radiation intensity tends to reach its peak for the day. This is because the sun is directly overhead therefore travels shorter distance through the sky to reach the earth surface compared to when it is at oblique position in the early morning. At this position the solar radiation attenuation at this time of the day as a result of cloud cover is very low, thus resulting in highest ambient temperature during this operation time (Adekunle *et al*., 2015). The ambient and solar collector reached their maximum temperatures 43.5°C and 65.4°C respectively at approximately 1pm, while the drying chamber reaches its maximum temperature 55°C slightly an hour after the solar collector peaks. Beyond 1pm, the temperatures begin to show gradual decrease, indicating the decline in solar radiation as the day progresses towards evening. The solar collector temperature is consistently higher than both the ambient temperature and the drying chamber temperature throughout the day. While the drying chamber temperature is lower than the solar collector temperature but higher than the ambient temperature during most of the day.

From the trend of three temperatures against time of the day shown in Figure 4, it is observed that there is a margin between the collector temperature and that of the drying chamber. The cause of the difference can be attributed to thermal mass which is phenomenon of the drying chamber construction material to absorb and store heat received from the air coming from the solar collector (Germain *et al*., 2021).

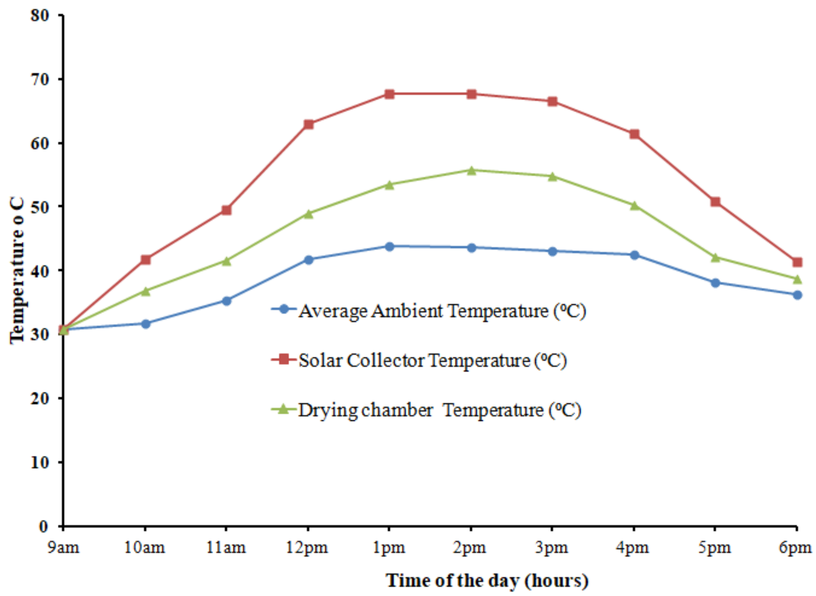

Figure 4: Temperature variation of the ambient, solar collector and that of the drying chamber during the operation hour

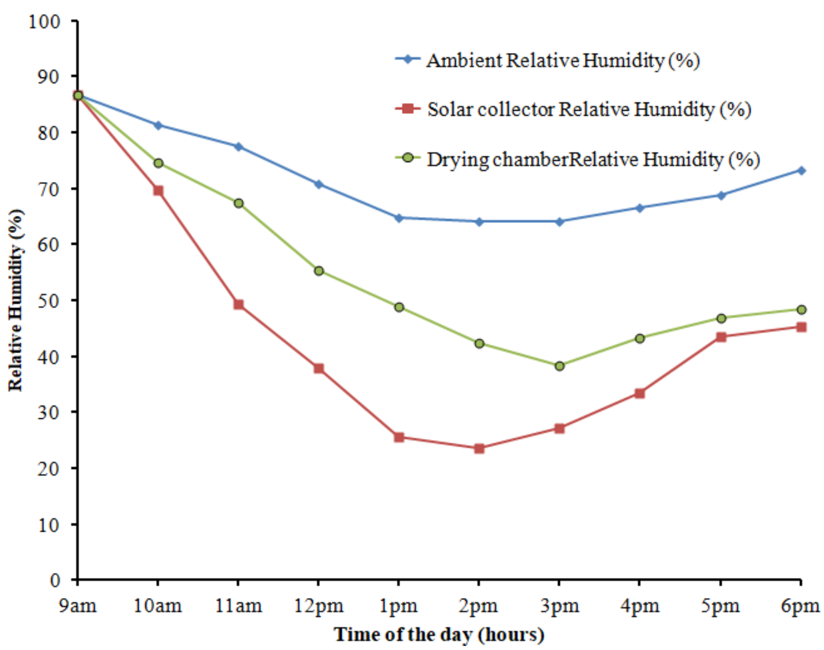

Figure 5: Relative humidity variation of the ambient, solar collector and that of the drying chamber during the operation hour

The relative humidity trends along the operation time of the day also shows that the average ambient, solar collector and drying chamber relative humidity started at the same point 87.7% at 9am in figure 5. From 9am to 1pm, ambient humidity gradually decreases to about 55%, while solar collector dropping sharply to its lowest point of around 22.6% and drying chamber also decreased from about 87.7% to around 35%. The decreasing trend suggests that the surrounding environment becomes drier as the day progresses with the change in the insolation inclination. This can be beneficial for drying process as it creates a moisture gradient that promotes moisture transfer from the drying material to the surrounding air. According to Aduewa *et al*., (2019) in their performance evaluation of automated solar powered hot-air supplemented dryer experiment in Akure, it was observed that the sharp decrease in relative humidity within the solar collector from morning until midday indicates effective heating and moisture removal. It was furthermore reported that this low humidity environment is ideal for drying as it promotes faster evaporation of moisture from the product. The ambient relative humidity remains relatively high throughout the day, which suggests that the solar drying system is working efficiently to reduce humidity within the system despite external conditions. The higher ambient humidity compared to the other two areas (drying chamber and solar collector) indicates that the drying system effectively isolates and manages internal humidity. The solar collector has the lowest trend of relative humidity throughout the day. The drying chamber also shows a similar trend but with slightly higher relative humidity compared to the solar collector. This could be attributed to effect of the drying chamber benefiting from the heat provided by the solar collector, leading to a substantial reduction in relative humidity, which is essential for efficient drying. Contrasting the temperature trends in figure 4 and relative humidity in figure 5, showed that as the temperature inside the solar collector and drying chamber increases to a peak around midday. Correspondingly, the relative humidity within these environments decreases as the temperature rises. This decrease in relative humidity as temperature increases is precisely what enhances the drying process. It ensures that the air inside the dryer remains unsaturated with moisture, continually drawing moisture out of the produce to be dried (Onigbogi *et al.*, 2012, Ángel *et al.,2020,* Alonge & Hammed, 2007).

Trend of energy absorbed by the air and solar collector efficiency

The energy absorbed by the air is a critical parameter that directly influences the performance of the solar collector. It represents the amount of heat gained by the air passing through the collector. While the collector efficiency represents the ability of the solar collector to convert solar energy into usable heat. The trends of the energy absorbed by the air and the solar collector are shown together in Figure 6, the energy absorbed by the air increases with increasing operation time. This trend is expected because the longer the air remains in contact with the solar collector, the more time it has to absorb solar radiation and gain heat. Consequently, as the operation time increases, the energy absorbed by the air also increases. The curve is relatively smooth, indicating that the energy absorption is generally consistent during the given time intervals. The energy absorbed by the air increased from 0.22kJ at 9.00 hour to 0.623kJ at 13.00 hour of the day, leveled fairly till 15.00 and declined significantly till 18.00 hour.

The collector efficiency also exhibits an increasing trend with increasing operation time. This trend aligns with the trend of energy absorbed by the air. As the solar collector operates for a longer duration, it has more time to capture solar energy and transfer it to the air passing through. Therefore, the efficiency of the solar collector improves over time. It is noteworthy that the collector efficiency does not increase linearly; rather, it shows a non-linear growth pattern. Initially, the increase in efficiency is moderate, but as the operation time continues to increase, the efficiency starts to rise more rapidly. This non-linear trend might be attributed to factors like the gradual warming up of the collector and the air stream, as well as the establishment of steady-state conditions in the system. Both the energy absorbed by the air and the collector efficiency increase with increasing operation time. Longer operation times allow the solar collector to better utilize solar energy and enhance its performance in converting sunlight into usable heat (Adelaja & Babatope, 2013).

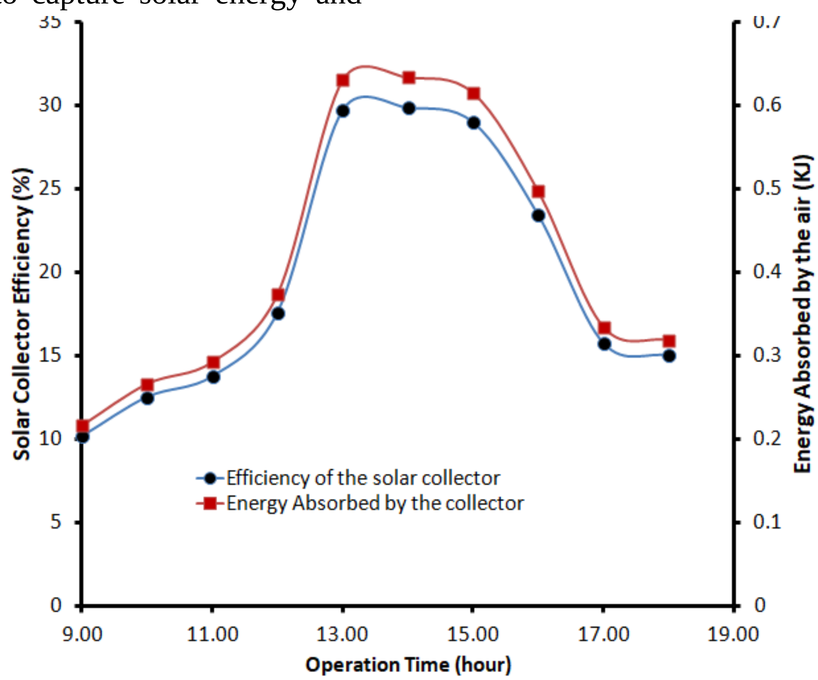

Figure 6: Energy absorbed and efficiency variation of the solar collector during the operation hours.

The declining trend towards the end of the daytime in both the energy absorbed by the air and the collector efficiency can be attributed to reduce Solar Irradiance. Towards the end of the day, the intensity of solar radiation decreases as the sun starts to set. The angle at which sunlight strikes the solar collector affects its efficiency. As the sun sets, the angle of incidence decreases, reducing the amount of solar energy effectively captured by the collector. As a result, the total irradiance received by the solar collector decreases. With lower solar irradiance, the amount of energy available for absorption by the air also reduces. This is reflected in the decreasing trend of energy absorbed by the air. Furthermore, the energy absorbed by the air is directly influenced by the temperature difference between the collector and ambient air. As the ambient temperature decreases during the evening, the temperature difference between the collector and the surrounding air diminishes. With a smaller temperature difference, the energy transfer from the collector to the air becomes less efficient, leading to a decline in energy absorption. Aremu *et al*. (2020) in their performance evaluation experiment of a hybrid solar dryer in Ibadan, Nigeria also reported decreasing temperature difference between the collector and the drying chamber at the evening period of 16.00 hour. Also study by Alonge & Hammed (2007), on direct passive solar dryer for tropical crops, they got the maximum temperature of 59ºC inside the dryer and 38ºC outside under no load test condition.

Performance evaluation the Indirect Active Solar Drying under loaded condition and under Open Sun Drying

At the start of the drying process shown figure 7, there is a significant drop in moisture content, which corresponds to a high drying rate. This is typical because, initially, the plantain surface has a high moisture content, making it easier for water to evaporate. Between 9:00 am to 12:00 pm on the first day of the experiment the weight of the plantain under the indirect active solar dryer IASD drops rapidly from 3.00 kg to 2.71 kg and the drying rate is approximately 0.16kg/hr.. Similarly, the plantain fillets under open sun drying (OSD) drops rapidly from 3.00 kg to 2.85 kg and the drying rate is approximately 0.12kg/hr. This indicates a high initial drying rate. As drying progresses, the moisture content within the plantain reduces, leading to a decline in the drying rate. The lower moisture content means that moisture must now migrate from the interior of the plantain fillets to the surface, a slower process due to internal diffusion limitations. By the end of the Day 1, IASD and OSD have removed 0.95kg and 1.46kg moisture respectively. This shows how efficient is the IASD compared to OSD

For the plantain under open sun drying, the weight decreases from 2.85kg at 12:00 pm to 2.05kg by 6:00 pm on Day 1, showing a slower rate of moisture loss. Similarly, for the plantain under the indirect active solar dryer, the weight decreases from 2.71kg to 1.54kg over the same period, but at a more rapid rate compared to OSD, indicating that the IASD still maintains a higher drying efficiency even in the falling rate period. By the 6pm of Day 2 (18th hour) of the experiment, the weight of the plantain under the IASD stabilizes at 1.05kg, indicating that the drying rate has slowed considerably, reaching a point where most of the free moisture has been removed.

In the later stages, the drying rate becomes very low as the plantain reaches its equilibrium moisture content, where further drying is minimal and primarily involves the removal of bound water, which requires more energy and time. For the plantain under the IASD, the weight stabilizes at 1.05kg, meaning the drying rate is near zero, indicating that the plantain has reached its final dryness level. The plantain under the solar dryer reaches its final weight of 1.05kg much faster than the plantain under open sun drying. This indicates that the IASD not only maintains a higher drying rate throughout but also reaches the critical moisture content required for safe storage much quicker. The IASD's ability to maintain higher drying rates translates to greater energy efficiency. This means that the solar dryer is a more effective use of solar energy, providing a higher yield of dried product in a shorter time. A faster drying rate effected by IASD positively impacted the quality of the dried plantain. Rapid moisture removal has been reported to prevent enzymatic and non-enzymatic browning, which are common issues in slower drying processes like OSD. The preservation of color, texture, and nutritional content is likely better in the solar-dried plantain.

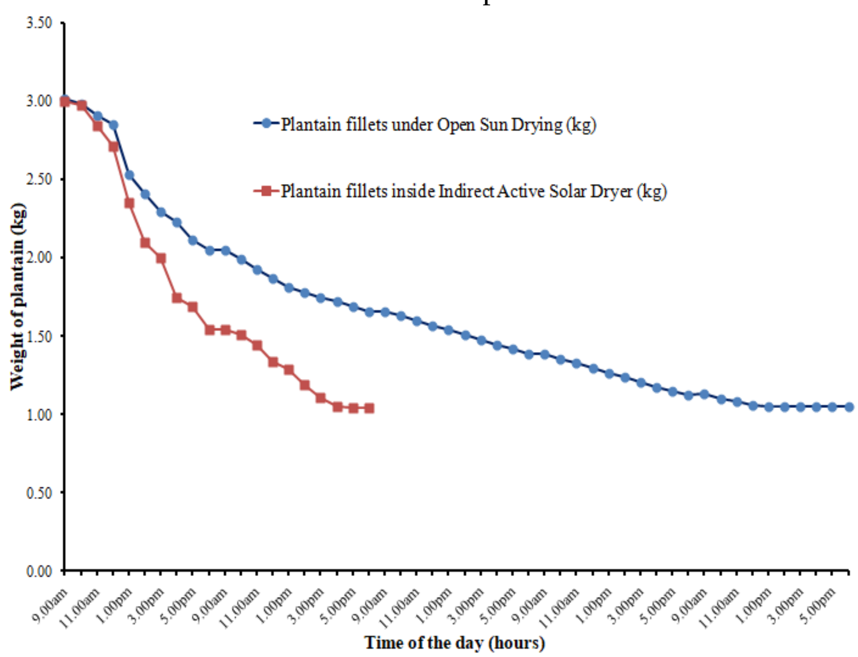

Figure 7. Trend of weight change of plantain fillets with time in solar dryer and open sun drying.

Percentage drying time salvaged

The Percentage Drying Time Salvaged quantifies how much faster the IASD achieves the final stable weight compared to OSD. The IASD was able to completely dry the plantain fillets to 15% moisture level at

18hours (6pm of Day 2), while the OSD recorded 45hours (6pm of Day 5) as shown in figure 7. The IASD reduces the drying time by 60% compared to open sun drying, demonstrating its significant efficiency advantage. This reduced drying time not only accelerates the drying process but also minimizes exposure to environmental contaminants, reducing the risk of spoilage. Studies have shown that solar dryers can significantly reduce drying time while maintaining or enhancing the quality of dried agricultural products, Ndukwu *et al.* (2020) found that solar dryers reduced drying time by up to 58% for fruits and vegetables, with improved quality compared to open sun drying. Similarly, Aduewa *et al.* (2016) reported that solar dryers can cut drying time in half while preserving the color, texture, and nutritional content of dried products.

Conclusions

The study on the performance of the Indirect Active Solar Dryer (IASD) under zero loaded conditions demonstrates significant advantages in temperature management, humidity control and overall drying efficiency. The hourly variation of the air temperatures inside the solar collector and that of the drying chamber are much higher than the ambient temperature. Similarly, the relative humidity of the air inside the collector and that of the drying chamber was significantly lower than that of the ambient. These two parameters indicate that the dryer exhibits sufficient ability to dry food product at a reasonably rapid rate. The energy absorbed by the air and the efficiency of the solar collector increased with operation time, highlighting the system's capacity to harness solar energy effectively. The declining trends towards the evening reflected the reduced solar irradiance, impacting both energy absorption and collector efficiency. Under loaded conditions, the Indirect Active Solar Dryer (IASD) outperformed open sun drying (OSD) in terms of drying rate and overall efficiency. The IASD not only reduced the drying time by 60%, but also maintained higher drying rates, resulting in quicker moisture removal and better preservation of the plantain's quality. The findings underscore the IASD's effectiveness in providing a controlled drying environment, minimizing exposure to contaminants and ensuring a higher yield of dried products in a shorter time. This makes the IASD a superior choice for enhancing the quality and efficiency of crop drying processes.

Furthermore, the data sets obtained during the loading of the dryer with plantain suggests that the drying process in the solar dryer effectively removes moisture from the plantain samples within a span of 19 hours operation time in 2days to safe moisture content levels. Monitoring the drying rate (percentage of moisture loss per hour) provides insights into how the dryer reduced the drying time by 60% when compared with open sun drying method.

Acknowledgement

We appreciate the research grant from the Tertiary Education Trust Fund (TETFUND) Nigeria, with Ref. No: TETF/DR&D/CE/FCE/AKOKA/IBR/2020/ VOL.1) which was used to fund this research

References

Adekunle, A.O, Emmanuel, C. O, Stephen B.O, and Fasanu, O (2015): Analysis of Global Solar Irradiance over Climatic Zones in Nigeria for Solar Energy Applications; *Journal of Solar Energy* (1)1-9. http://dx.doi.org/10.1155/2015/819307

Adelaja, A. O. and Babatope, B. I. (2013). Analysis and testing of a natural convection solar dryer for the tropics. *Journal of energy*. (4):1-8. http://dx.doi.org/10.1155/2013/479894

Afolabi, T. J., and Agarry, S. E. (2014). Modeling of drying kinetics of untreated and pretreated plantain (Musa paradisiaca) chips. *Journal of Food Processing and Preservation*, 38(1), 118-126.

Akinola, T. A., and Akinyemi, O. T. (2012). A comparative analysis of traditional and solar drying methods. *Journal of Agricultural Technology*, 8(3), 739-753.

Alonge, A. F and Hammed, R.O (2007). A direct passive solar dryer for tropical crops. African Crop Science Conference Proceedings, 18: 1643-1646.

Ángel C.S, Leontina L, Marina C.L, Abdolreza K, Klaudia M, Ángel A. C and Adam F (2020): Comparison of Traditional and Novel Drying Techniques and Its Effect on Quality of Fruits, Vegetables and Aromatic Herbs. *Foods*(9)1-27. doi:10.3390/foods9091261

Arah, I. K., Kumah, E. K., Anku, E. K., and Amaglo, H. (2015). An overview of post-harvest losses in tomato production in Africa: Causes and possible prevention Strategies. *Journal of Biology, (5*) 78–88.

Aremu, O. A. Odepidan, K.O. Adejuwon, S.O, Ajala, A.L. (2020): Design, fabrication and performance evaluation of hybrid solar dryer. *International Journal of Research and Innovation in Applied Science* (IJRIAS) | (5) 159-164

Dabai, K.A, Garba, I., Adamu, A.A., Buda, S. and Argungu, G.M (2018). Determination of optimum tilt angles and its effect on solar radiation for solar collectors for some locations in Africa. *Nigerian Journal of Renewable Energy*.18 (1&2): 1 – 12

Desta B (2021): Role of Postharvest Management for Food Security: *A Review. Advances in Crop Science and Technology*. 9(7):1-6

Elhage H, Herez A, Ramadan M, Bazzi Hassan and Khale, M. (2018). An investigation on solar drying: *A review with economic and environmental assessment. Energy*, 157: 815-829.

FAO. (2019). The State of Food and Agriculture 2019: Moving Forward on Food Loss and Waste Reduction. Food and Agriculture Organization of the United Nations.

Femi, O. (2022) Post harvest losses and food security in Nigeria: An empirical review. *African Journal of agriculture and food science*, 5(3); 77-89. https://sinovoltaics.com/learning-center/system-design/solar-panel-angle-tilt-calculation

Germain, W.P O, Boureima K, Bienvenu, M.P, Kalizeta S, Vincent Z, Sié K, Dieudonné J. B (2021). Thermal Analysis of a Solar Dryer with Parabolic Collector. Science . Vol. 9, No. 6, 2021, pp. 127-131. doi: 10.11648/j.sr.20210906.15

Gutti, B, Kiman, S and Mustafa, B.G (2012). Design and Construction of Forced/Natural Convection Solar Vegetable Dryer with Heat Storage. *ARPN Journal of Engineering and Applied Sciences*, 7(10): 1213 – 1217.Joardder, M. U., Karim, A.,

Kumar, C., and Brown, R. J. (2015). *Porosity: Establishing the Relationship Between Drying Parameters and Dried Food Quality*. Cham: Springer. Kapadiya S and

Desai M.A (2014). Solar drying of natural and food products: A review. International Journal of Agriculture and Food Science Technology, 5: 565-576.

Kumari A, Singh R, Prakash O and Shutosh A (2014). Review on global solar drying status. Agricultural Engineering International CIGR Journal, 16: 161-177.

Madhlopa, A., Jones, S. A., & Saka, J. D. (2002). A solar air heater with composite-absorber systems for food dehydration. *Renewable Energy*, 27(1), 27-37.

Oguguo A.C (2004). Post harvest losses, major cause of food insecurity. The Guardian Newspaper, 025 April, pp 3

Okonkwo H.O. and Ertekin C. (2022). Review on Solar Drying in Nigeria. Turkish Journal of Agricultural Engineering Research (TURKAGER), 3(2), 397-429. https://doi.org/10.46592/turkager.1060019

Oloruntoba, D. S., Afolabi, T. J.,and Bamigboye, A. O. (2020). Development and Performance Evaluation of a Passive Solar Dryer for Plantain Chips. *Journal of Solar Energy Engineering*, 142(3), 031003.

Oloruntola, M., Folorunso, A., Bayewu, O., Mosuro, G., and Adewale, S. (2019). Baseline evaluation of freshwater–salt water interface in coastal aquifers of Badagry, South-western Nigeria. Applied Water Science, 9(85), 1–14. h t t p s : //d o i . o r g /10 .10 0 7/s1 3 2 0 1- 0 19 - 0 9

Oguguo A.C (2004). Post-harvest losses, major cause of food insecurity. The Guardian Newspaper, 025 April, pp 3

Onigbogi I.O, Sobowale, S. S and Ezekoma, O.S (2012): Design, construction and evaluation of a Small Scale Solar Dryer. Journal of Engineering and Applied Science. Volume 4, pp8-21

Sawicka, B. (2019). Post-harvest Losses of Agricultural Produce. In: Leal Filho, W., Azul, A., Brandli, L., Özuyar, P., Wall, T. (eds) Zero Hunger. Encyclopedia of the UN Sustainable

Development Goals. Springer, Cham https://doi.org/10.1007/978-3-319-69626-3_40-1

Sarwar, M. (2020): Impact of Post-Harvest Loss (PHL) on Food Security: Perspectives from Bangladesh. Paper presented at postharvest institute Illinois, USA. February 5th, 2020

Sharma, A., Chen, C. R., and Vu Lan, N. (2009). Solar-energy drying systems: A review. *Renewable and Sustainable Energy Reviews*, 13(6-7);1185-1210.

Simate, I. N. (2003). Optimization of mixed-mode and indirect-mode natural convection solar dryers. *Renewable Energy*, 28(3); 435-453.

http://theworldofinfo.com/nigeria/geography/ accessed 20th June, 2023

http://en.wikipedia.org/wiki/Nigeria accessed 20th June, 2023

Nigeria - Solar irradiation and PV power potential maps | Data Catalog (worldbank.org)