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A Review of Hybrid and Green House Type Solar Dryers

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ABSTRACT

Solar drying is a renewable, efficient, cheap, and sustainable method of preserving agricultural produce. Recent trends in hybrid and greenhouse–type solar dryers were studied. The study revealed that hybrid and greenhouse–type dryers are robust and efficient because they are mostly embedded with heat generating and circulation systems. They are designed to accommodate large-scale drying of fruits and vegetables with higher rates of drying, reduced drying time and some other specific advantages. Findings also revealed that hybrid and greenhouse type solar dryers are mostly designed for optimum retention of heat to compensate for periods with low illumination. The study also gave insight into design challenges peculiar to these types of dryers, and further revealed that most of the fabrications were based on assumptions, with limited data as references. This review also highlights the cost of procurement, uniformity of airflow, sizing of blower and material selection as some of the factors limiting the utilization of hybrid and greenhouse type solar dryers for drying of fruits, vegetables, and other staple crops.

Keywords: *Solar drying, Greenhouse solar dryers, Hybrid solar dryers, Fruits, Vegetables*

INTRODUCTION

Drying is essential for the preservation of food, reducing microbial loads, and maintaining the physical and textural properties of the food. According to a survey by FAO (2017), between 40 to 60% of staple crops, fruits and vegetables harvested is lost annually in most parts of Africa, due to the inability of local food producers to develop adequate technology for post-harvest handling of their produce. However, this may not be the case in other climes as they have over time deployed sustainable means of drying and preserving harvested products. Solar drying is a superior alternative to open sun drying, as the latter is characterized by theft, infestation by animals, hygienic concerns, etc. These shortcomings are addressed to some reasonable extent when products are dried using hybrid and greenhouse type solar dryers, because of the enclosed nature of the dryers. Mohammed *et al.* (2020) compared traditional solar drying systems to improved solar drying systems using some fruits as case studies. Their study revealed that the solar systems tested have the potential of preserving the quality and sensory properties of the dried fruits better than open sun drying, which were reported to be contaminated because of their exposure to the atmosphere. Udomkun *et al.* (2020) examined solar dryers for agricultural products in Asia and Africa, using an innovative landscape approach. Their findings revealed that solar drying is cost–effective and capable of preserving the quality of harvested products in sub-Sahara Africa and Asia. They also concluded that despite the high initial cost required for its development; hybrid and greenhouse type solar dryers come with huge economic returns.

Hybrid and greenhouse type solar dryers are robust and generally enhance the drying process better than open sun drying. The dryers are mostly embedded with heating medium and blower to enhance circulation of hot air within the drying chamber for rapid drying of products. Several researchers have worked on hybrid and greenhouse type solar dryers and reported higher efficiencies as against other systems like indirect, direct, and mixed mode solar dryers, because some of the systems are developed to work round the clock, despite low radiation and temperature (Almuhanna, 2012; Cesar *et al.*, 2015; Barade *et al.*, 2016; Madhava *et al.*, 2017; Etim *et al.*, 2019; Mohsen *et al.*, 2019). Janjai and Bala (2012) observed that recent developments and use of solar dryers such as greenhouse type solar dryers, roof based integrated dryers, and tunnel type dryers in drying agricultural products such as fruits, vegetables, species, medicinal plants, and fish have greatly improved their quality.

This review will attempt to outline some of the developments in hybrid and greenhouse-type solar dryers and highlight gaps for possible research opportunities in the future.

SOME RECENT ADVANCEMENTS IN HYBRID SOLAR DRYERS

Various kinds of solar dryers were developed in the last three and half decades. These include: Active direct solar dryers (Alonge and Uduak, 2014); and active indirect solar dryers (Alonge and Jackson, 2014) as shown in Figures 1 and 2 respectively. A combined direct-indirect solar dryer (Figure 3) also known as mixed mode was developed by Alonge *et al.* (2020) and used for drying of fruits and vegetables. This dryer had similar features to dryers developed by Afzal *et al.* (2023) and Duque-Dussán et al. (2023).

Figure 1. *A direct active solar dryers (Alonge and Uduak, 2014).*

Figure 2. *Indirect active solar dryers (Alonge and Jackson, 2014).*

Figure 3. *Mixed mode solar dryer (Alonge et al., 2020).*

Amer *et al.* (2010) designed a hybrid solar dryer for bananas and tested it for its performance. A heat exchanger was attached to the dryer for optimal air circulation. The drying time of the product was reduced by almost 50% when compared to open drying. Poonia *et al.* (2018) fabricated a (Pressure, Volume/Temperature) PV/T hybrid solar dryer. The system was designed to combine both electrical and thermal energy for the drying process. The dryer as shown in Figure 4, consisted of a collector unit, drying chamber, (Direct Current) D.C. fan, (Photovoltaic) P.V. panel, and a PCM chamber, which aided storage of thermal energy. The PV panel attached to the dryer supplied the blower with the required power to ensure optimum circulation of air in the drying chamber. Three mathematical models, namely: Henderson and Pabis, Lewis and Page, were used to predict the drying process.

Figure 4. *PV/T hybrid solar dryer (Poonia et al., 2018).*

Murali *et al.* (2020) designed a hybrid solar dryer for shrimp drying. The study focused on designing a solar system that will ensure continuous drying operation irrespective of the time of the day. The drying and maximum collector efficiency obtained were 37.09% and 42.37%, respectively. The drying time was reduced by more than half when compared to the open sun experiment. Yahya (2016) developed a solar–assisted heat–pump dryer integrated with a biomass furnace for drying red chilli. The dryer had a blower with a capacity of 0.75kW used in the circulation of air and had three layers of drying as shown in Figure 5. The dryer reduced the time of drying by 82% when placed side aside with open sun drying. The performance of the dryer was computed as a function of the rate of drying, moisture removal rate, and efficiency of the dryer. The performance of the dryer was dependent on components such as solar collector, heat pump and biomass furnace. Their study however reported some degree of uncertainty in experimental data due to factors like selection of instrument and conditions of the environment. Etim *et al.* (2023) reported similar concerns.

Figure 5. *Solar assisted heat pump dryer integrated with biomass furnace (Yahya, 2016).*

Aremu *et al.* (2020) developed a hybrid solar dryer and tested it for performance. The system was embedded with a collector, drying chamber and three trays of 1.3 × 1.4

m dimension. Four solar photovoltaic (PV) cells, which served as a heating element charged the tubular battery and powered the blower. The dryer was observed to have reduced the time of the drying and achieved better efficiency as compared to open sun experiments and other dryers tested without attaching the external energy source. Hussien *et al.* (2017) developed a photovoltaic hybrid solar dryer. The dryer was embedded with a drying chamber, racks, trays, heater, blower, solar panel, D.C. battery, and charge controller. The drying chamber was of 0.30 m^3 volume and the distance within the trays was 0.1 m. Materials considered were mild, galvanized steel and plywood. Figure 6 shows a picture of the dryer as constructed, with solar panels attached to supply the power needed to activate the blower. The hybrid solar dryer reported an increase in drying chamber temperature from 38 to 62°C, while the temperature of the control experiment (open sun) did not exceed of 45°C during the peak period of solar radiation (12-2pm). They argued that the efficiency of dryers could be enhanced by combining solar and heating element coils powered by a PV panel as compared to biomass heating sources.

Figure 6. *A hybrid photovoltaic (PV) solar dryer (Hussien et al., 2017).*

Padhi and Bhagoria (2013) developed a mixed-mode forced convective solar dryer. A smooth and rough plate solar collector was attached to the dryer. The roughness of the absorber underside enhanced heat transfer within the drying chamber. The dryer was observed to have achieved drying within four days, as against eight days which was the case of the control experiment (open sun). Yunus and Al-Kayiem (2013) simulated a hybrid solar dryer. They averred that the dryer's performance was dependent on effective thermal heat flow in the inner chamber of the dryer. The simulation process was considerably in agreement with data from the experiment, although the high temperature spot showed the low circulation of air, portraying the design as faulty. Etim *et al.* (2020) designed an air indirect mode solar dryer. The focus of their design was to examine the effect of the air inlet vent on the performance of the dryer. It was repeated that the dryer performance was dependent on the air inlet area. They observed that the dryer was able to reduce the drying time by 40%. The solar dryer was optimized for efficiency, and a further reduction of the drying time by 65% was achieved (Etim *et al.,* 2021).

Shaikh and Kolekar (2015) reviewed several hybrid solar dryers and made quite the same significant observations. They observed that in most underdeveloped countries, farmers depend hugely on open sun for drying harvested products. They argued that practices of this sort affect the quality of dried products, enhance the infestation by impurities, and promote uneven drying rates. They observed that the high cost associated with hybrid mode solar dryers, despite its ease of fabrication and usage, has led to a deviation of interest from advancing the use of the system for drying agricultural products, one of such being a hybrid solar dryer developed by Saravanan *et al.* (2014) as shown in Figure 7. They advised the use of low-cost materials that are particular to the environment of the drying for the fabrication of hybrid solar dryers to enhance acceptability and usage. Similar observation was made by Lamrani *et al.* (2022).

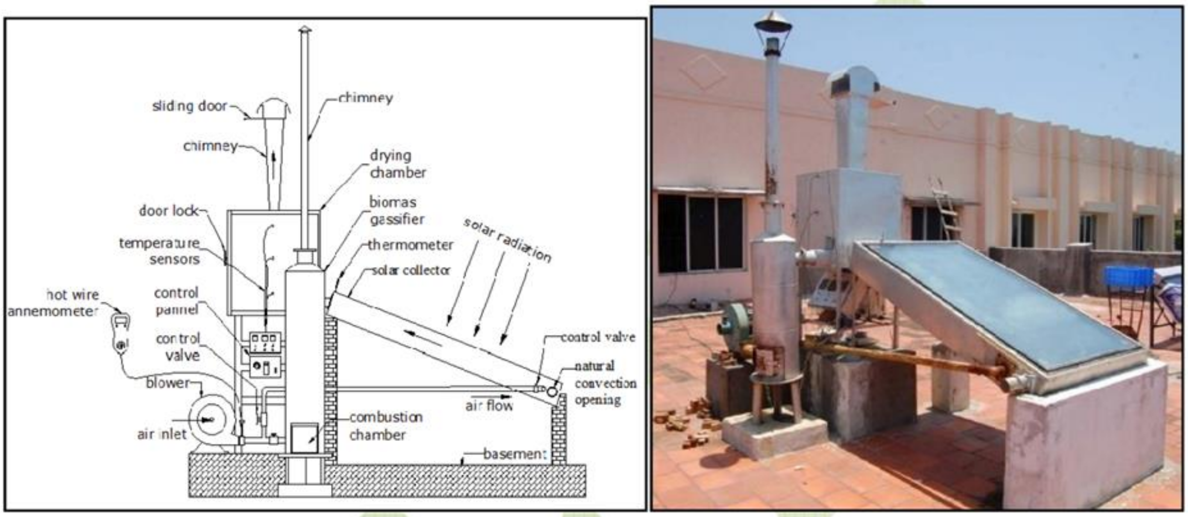

Figure 7. *Hybrid solar dryer (Saravanan et al., 2014).*

SOME RECENT ADVANCEMENT IN GREEN HOUSE TYPE SOLAR DRYERS

Prakash and Kumar (2014) designed, developed, and tested a greenhouse type dryer modified with conditions of natural convection. Their study was aimed at examining the performance of the dryer based on factors such as heat loss, diffusion, heat transfer, and thermal efficiency. To preserve heat, the wall of the dryer was designed with an opaque feature.

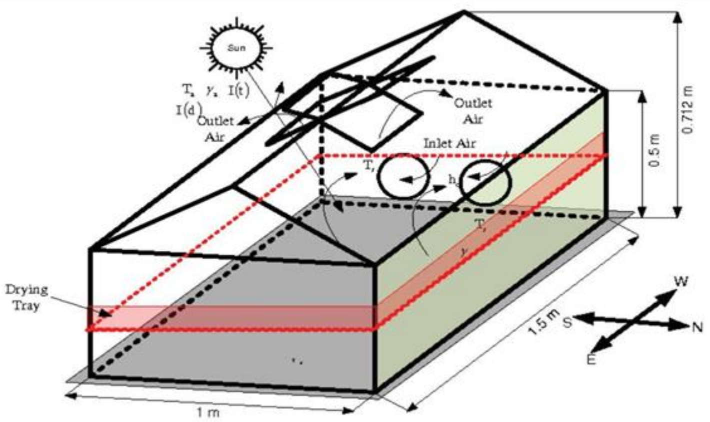

Figure 8. *Skeletal view of a modified greenhouse type developed by Parkash and Kumar (2014).*

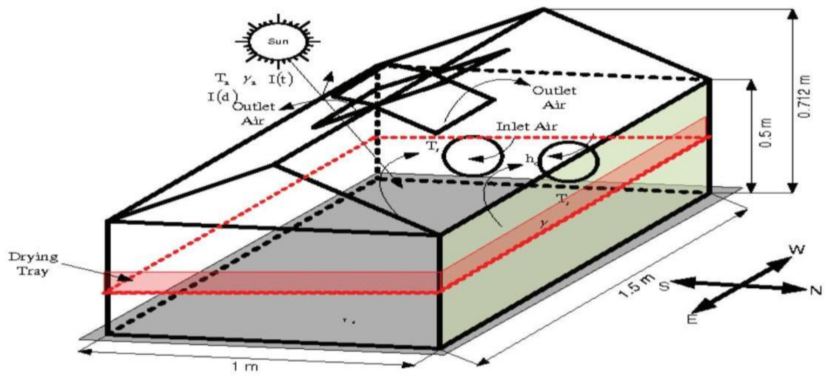

Figure 9. *Skeletal view of a modified greenhouse type with a black PVC cover material, developed by Parkash and Kumar (2014).*

Two sets of experiments were conducted for the respective dryers, the first seeing the greenhouse rest of a sandy ground (Figure 8). The floor of the dryer was covered with a sheet of black plastic (Figure 9). The latter was discovered to be more efficient than the former, because the black PVC aided the retention of heat inside the dryer.
Barnwal and Tiwari (2008) designed, constructed, and tested a hybrid photovoltaic integrated greenhouse dryer for performance. The solar radiation incident on the glass of the PV module produced the heat required to increase the temperature of the greenhouse for smooth operation. The radiation was converted to a DC electric system, which was used to power a blower for efficient circulation of hot air within the chamber. They also designed a similar system but used polythene as a collector/covering material in place of glass and it was operated by a non–convective force principal. Both dryers are shown in Figure 10.

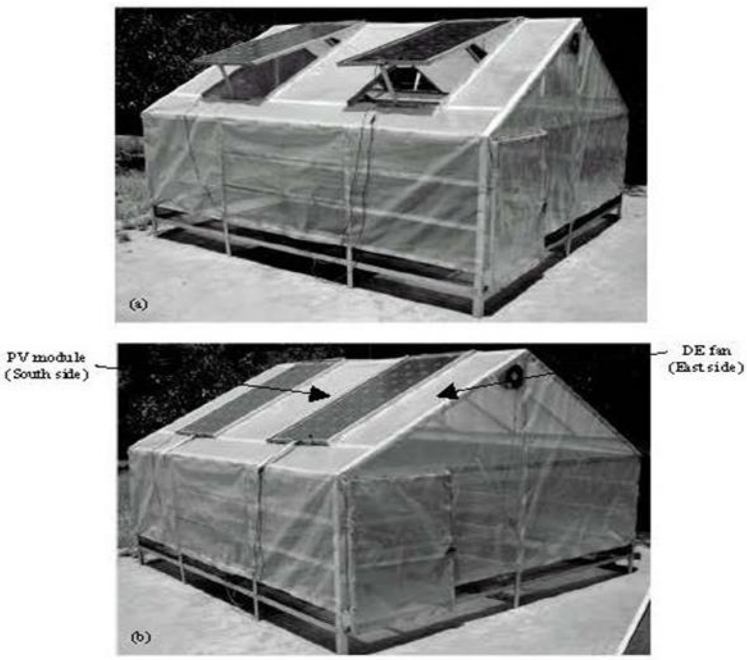

Figure 10. *Natural convection and forced convection hybrid photovoltaic integrated green house dryer (Barnwal and Tiwari, 2008).*

It was observed that the forced convective drying system was of slight advantage than the natural convection type, as there was even distribution of hot air inside the dryer which also helped in maintaining the desired drying temperature. They concluded that the thermal loss efficiency of the dryer was reduced by 80%.

Nguimdo and Noumegnie (2020) designed an automatic hybrid solar dryer for households for staple crops in Cameroon. They posited that post-harvest losses in the Central African nation were because of drying systems that could help in preserving the quality of what is harvested by locals. The efficiency obtained from the hybrid system was higher than that of the passive solar system. The variation was attributed to the more efficient circulation of hot air in the drying chamber aided by the blower.

Hempattarauwan *et al.* (2019) designed a parabolic green–house type dryer for drying of cayene pepper and tested it for its performance. The dryer was of base area of 48 m^2 and height of 3.25m. It was designed to dry between 100 to 200 kg of the product in less than 50% of the time that would have been taken to dry a similar quantity of product using the open sun drying method. The dryer, which was embedded with a 50W solar cell module, powered three DC fans, and was also observed to have had more reliability in terms of preservation of the final quality of the product as against natural convection means of drying.

Janjai (2012) developed a greenhouse type solar dryer for small-scale drying in the Food Industry. The dryer was made of a parabolic roof structure covered with polycarbonate sheets on a concrete floor. The width of the dryer was 8m, length 20m and height was 3.5m. The dryer (1000 kg loading capacity) was fitted with nine 15W D.C. fans powered with the aid of a 50W P.V. module to ventilate the dryer. Experimental data averred that the temperature in the drying chamber increased 35 to 65°C while drying was achieved between two to three days, relatively shorter than what should have been obtained if the products were dried using natural sun drying. Puello-Mendez *et al.* (2017) comparatively studied the drying of cocoa beans in rural communities of Colombia. The dryer used (Figure 11) was 2.0 m in width, 5.0 m in length and 2.2 m in height. The cover material used was polyethylene film of 2.0 mm thickness.

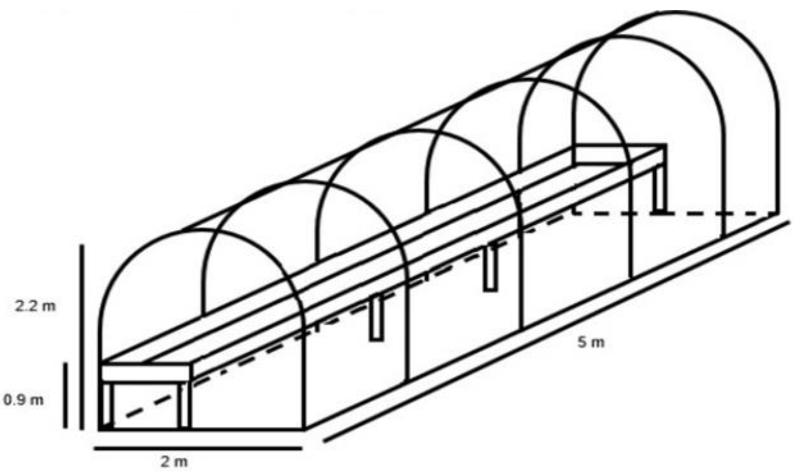

Figure 11. *Interior view of a Green House type solar dryer developed by Puello-Mendez et al. (2017).*

The dryer was observed to have reduced the duration of drying by two days when compared to the six days required to dry the same amount of product (2 kg) using natural sun. The moisture level of the product reportedly decreased rapidly within 48 hours of consistent drying, but gradually decreased on the third and fourth day, with corresponding increases in the drying time.

Ndirangu *et al.* (2020) analysed various designs of existing solar green–house type dryers in Kenya and appraised their performance. Eighteen dryers were assessed in the process and the length, width and height averaged 8.12, 3.95, and 2.37m, respectively. The analysis was based on key factors including: the design; construction materials; configuration and cost–benefit ratio. It was reported that more than 20% of the dryers were characterized by losses above 10% due to environmental conditions, ventilation concerns and spillage. About 65% of the dryers were reported to have been made of gabble roof structure (Figure 12), while 23% were of parabolic shape. The remainder could not be traced to any specific shape configuration. They opined that the gabble of type–solar dryer was preferred to others because of its simplicity to construct, ease of maintenance, cost, and other common features.

Kaewkiew et al. (2012) investigated the performance of a large-scale greenhouse type solar dryer for drying chilli. The dryer was 8.0 m in width, 20.0 m in length and a height of 3.5 m. It was parabolic in shaped. The experiment conducted using 500 kg of chili revealed that the moisture level reduced from an initial 74% (wet basis) to a final moisture level of 9 % (wet basis) within 72 hours of drying. When compared to open sun drying, the product could only reduce its moisture content to 66% within the same time frame. The positioning of the trays in the dryer had no significant effect on the quality of the final product.

Nurhasanah *et al.* (2018) developed a green-house-type dryer for red onion bulb leaves. The dryer was 6 m long, 3 m wide, and 6 m height. The roof was made of transparent fiber glass equipped with an aeration wall. A heat exchanger was also embedded into the dryer to optimize the flow of hot air within the dryer for faster drying of the product. Experiments conducted revealed that 1000 kg of red onion bulb leaf with an initial moisture level of 87% recuced to 14% (wet basis) within 35 hours. This was economical for large scale operations, as against open sun drying which would require double the time. Another significant advantage of the dryer as reported was its ability to work optimally irrespective of seasonal variation.

Roman-Roldan *et al.* (2019) analysed the heat transfer propoerties of a greenhouse solar type dryer embedded with an air heating system. The dryer (Figure 12) was of 6 m width, 5 m length and 4 m height. The dryer had two inlets and two outlet points to enhance the circulation of hot air during the drying process. The system was observed to have been 60% more efficient than the control experiment (open sun) and recommended for drying the products withintemperature not more than 70°C.

Figure 12. Greenhouse solar dryer embedded with air solar heating device showing air inlet (a) and outlet (b) (Roman-Roldan et al., 2019).

Intawee and Janjai (2011) have designed and evaluated the greenhouse solar dryer made with polyethylene as cover material. The dryer was of 7.5 m width, 20.0 m length and a height of 3.7 m. It was designed to handle 1000 kg of product per batch. Six number direct current fans were attached to the dryer for optimal circulation of hot air within the drying chamber. The blowers were powered using three 50W solar cell modules. Readings from the experiments were taken with the aid of a digital data logger. The dryer (Figure 13) was used to dry chili and banana and the result from the experiments showed that the moisture level of the product (chili) reduced from 76% (wet basis) to 10% (wet basis) within 72 hours, whereas, the moisture content of chili of the product exposed to open sun experiment could not be reduced to 44% within the same period (72 hours). Similar result was recorded for banana samples which were also subjected to drying on the dryer.

RESEARCH GAPS

Figure 13. Interior view of a greenhouse dryer for drying chilli (a) and banana (b) (Intawee et al., 2011).

This review has highlighted a few gaps, which are rather technical and a complete deviation from the initial installation cost, which researchers attribute limited utilization of hybrid and greenhouse-type dryers to. From the study, most designs based the width, length and height of greenhouse-type dryers on assumptions, without necessary recourse to the quantity of product to be dried and considerations for the design of the drying chamber. In some cases, the dimensions (length, width and height) informed the sizing of the drying chamber, and considerations not made for loading and unloading of the product in the dryer.

Another critical concern observed was the uniformity of the air flow in the drying chamber. From the several studies examined, the positioning of the blowers (DC fans) may not affect the overall performance of the dryer, but aid in the fast drying of product in segments where they were placed, while drying gets optimal in other segments of the chamber with time.

Adequate sizing of the blower is also key. It was observed that the blowers used for the dryers reviewed were based on assumption. The air–flow rate within the drying chamber and outside should have been considered in many of the designs, to allow for proper sizing of the fans. The fans should also be dependent on the capacity of the dryer and should be used as the basis for determining the amount of power required for optimal operation.

Most of the greenhouse type dryers were of parabolic shape, while a few preferred the roof type. Most of the fabricators preferred the parabolic type because of its initial cost and maintenance options. The parabolic shaped dryers were reported to be more efficient because of their configuration, which aids in more direct penetration of solar radiation. Most of the dryers were observed to have been constructed with polyethylene, as against more heat–retaining materials like Perspex. The choice of cover material is of relevance, given environmental and other factors. In summary, the design of most greenhouse type solar dryers is based on assumptions and factors the design engineer considered relevant for the design.

CONCLUSION

Hybrid and greenhouse type solar dryers are more efficient than passive and active solar drying systems. These systems should be utilized to minimize post–harvest related losses in fruits and vegetables. Local materials that are more efficient and available can be deployed to serve the purpose since the cost of acquiring some of the materials reviewed was relatively higher. The initial cost of acquiring a hybrid and green-house type is significantly high. However, it is strongly recommended that farmers who are into production of crops of similar characteristics, which require drying and removal of moisture content for prolonged shelf life, should form themselves into cooperatives and acquire a large scale dryer to help in cost reduction and profit maximization. Similarly, prior attention should be paid to the dimensions, sizing of air heating and circulation medium when designing a hybrid and greenhouse-type solar dryer to ensure optimal performance.

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DECLARATION OF COMPETING INTEREST

The authors declare that they have no conflict of interest.

CREDIT AUTHORSHIP CONTRIBUTION STATEMENT

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David ONWE: Writing-original draft, review, and editing
Inimfon OSSOM: Writing-original draft, review, and editing.

ETHICS COMMITTEE DECISION

This article does not require any ethical committee decision.

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