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Design of a Friendly Solar Food Dryer for Domestic Over-Production

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Highlights:

What are the main findings?

- Using low-cost and reused materials it is possible to design and construct clean and cheap solar dryer prototypes;
- Drying kinetics in different products on our prototypes prove to be similar compared to an electric commercial dryer;

What is the implication of the main findings?

- Solar dehydration of vegetables and fruits over-production greatly reduces waste and the costs of final products;

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Abstract: Solar drying is one of the many ways of efficiently making use of solar energy to meet the human demand for improved sustainability. In this study, we describe the construction and testing of two indirect solar dryer prototypes, especially designed for vegetables and fruits. The dryers had two compartments: a solar panel and a drying chamber. The dryers were mainly made of wood (Prototype 1) and styrofoam (Prototype 2) and both used recycled aluminum cans. The calculated yield of solar panels was 82% and 77% for Prototype 1 and 2, respectively. The drying tests performed with different fresh products showed that it was possible to dry all of them until less than 10% of their initial weight, at different times, depending on the type of product. As regards the apple slices, the solar dryers were able to remove 95.7% and 95.0% of initial moisture on a wet basis for Prototype 1 and 2, respectively. Comparative tests were conducted with an electric commercial dryer using the same product to explore the drying dynamics and costs. The cost of the final dry product, excluding the purchase of fresh goods, was 6.83 €/kg for the electric dryer, 1.78 €/kg for Prototype 1 and 1.72 €/kg for Prototype 2. Dehydrated apple slices are currently available on the market for around 34.50 €/kg. Our solar dryers can dry quality products at a very low cost for their entire life span, which allows them to compete with electric systems to prevent food waste in a cheaper and environmentally friendly way.

Keywords: solar energy; indirect solar dryers; comparative studies

1. Introduction

One of the challenges affecting fruit and vegetable small producers is the destination of the goods they cannot consume or sell. This is especially exacerbated when harvesting periods are very short and products have high rates of deterioration [1]. Freezing is usually the first solution, but it causes storage difficulties and does not prevent the degradation of nutrients and organoleptic properties [2]. Another usual option is the manufacture of jams and jellies, with addition of high amounts of sugar, resulting in a less healthy product. Dehydration is one of the oldest techniques of food preservation still widely used for preserving figs, grapes, or fish, in a passive and direct mode, despite it being time-consuming and the fact that food is often contaminated by dust, insects, fungi, and bacteria [3]. However, it lowers the cost of packaging, storing and transportation by reducing the final weight and volume. Recently, small home electric dehydration systems have appeared on the market, but they have proven to increase energy costs.

The source of solar energy on the planet is the sun that powers the entire world. The solar constant, i.e., the extraterrestrial total solar irradiance per unit area measured on a surface perpendicular to the rays, at one astronomical unit from the sun, is estimated to be around 1353 W/m^2 [4]. This value ranges from 1412 kW/m^2 in early January to 1321 kW/m2 in July due to the Earth's varying distance from the sun. Approximately 165 petawatts (PW) of solar energy is received on the Earth's surface. A total of 30% of this energy is reflected into space, while 47% is converted into low-temperature heat (water evaporation, 23% into wind, and waves kinetic energy, 0.5%) [5]. Nowadays, we are facing severe changes in the way we use energy, giving priority to renewable and clean energy sources instead of using fossil fuels to produce electricity. To decrease the contribution to climate change and the cost of energy acquired from the grid while also minimizing post-harvest damage, the use of direct solar energy in processes like dehydration is expected to play a major role in food preservation [6].

Post-harvest fruits and vegetables need a preservation method to avoid losses, which can be very high in a short time due to their sugar and water contents that facilitates the attack of microorganisms leading to their easy deterioration. Foods can be spoiled by food microorganisms or through enzymatic reactions within the food. Bacteria, yeast, and molds must have enough moisture around them to grow and cause spoilage. In the food drying process, the natural water content is reduced, preventing the growth of these spoilage-causing microorganisms, and slowing down enzymatic reactions that take place within food [7].

Drying food appears to be easy and cheap. However, the use of high temperatures or the exposure to oxygen can compromise the nutrients, especially vitamins, because they are more sensitive to temperature rises [8]. To successfully dry food at home, we need a heat source to force out moisture without cooking; dry air to absorb the moisture that is released; and air movement to remove the moisture. For that, we can use a ventilated kitchen oven, a commercial food dehydrator, or a sun dryer. A dryer must dehydrate products from their initial humidity, above 80% to below the level necessary for their conservation, less than 10%. The process must be efficient, environmentally friendly, simple in its construction, and recommendable for the post-harvest treatment of a variety of goods [9]. A solar dryer can reduce production costs, energy consumption, and waste because it uses non-standard quality fruit for consumption and occupies little space, making it an alternative for small and medium producers [10] and domestic utilization.

Regarding conventional drying, different designs and methods have been described, such as convective hot air [11–13], force convection [14], non-thermal ultrasonic [15], osmotic [16], infra-red [17,18], microwave [19], among others.

Solar dryers are usually classified according to three parameters:

(i) Air movement.
(ii) Heat transfer.
(iii) Type of drying chamber.

In terms of air movement, there are the passive systems, with natural convection [20] or active systems with forced convection using fans [21].

There are four types of heat transfer:

(1) Direct, normally with low-cost construction, composed of a drying chamber covered by a transparent glass or plastic. The main disadvantages are the large amount of space needed to its installation and the doubtful quality of the products due to the direct exposition to sun [22].

(2) Indirect, with a solar panel and a drying chamber. The air is warmed in the solar panel and conducted inside the drying chamber, transferring heat to the material, and evaporating the moisture. They are more effective than the direct type; the drying rate is higher, air velocity and temperature can be controlled, and the products quality is preserved. Nevertheless, this system can be more expensive [23].
(3) Mixed solar dryer, which uses both direct and indirect solar energy. A separate collector preheats the air before it enters the drying chamber, and the sun helps heat the products. This system could be more powerful but is more complex and expensive [24].
(4) Hybrid solar dryer, combines other heating processes (fossil fuel, biomass or electric) with solar heating. The major advantage is that it can operate without solar energy, or during the night. It reduces the drying time compared to other transfers described. However, it has an increasing environmental footprint and running costs [25].

As to drying chambers, two types are reported: the greenhouse solar dryer and the cabinet type. The first combines the solar collector with the greenhouse system [26]. The structure is made of transparent material but has a black surface to enhance solar radiation absorption. The second consists of a large box made up of simple materials like metal or wood. It dries the products on trays inside of the chamber and may be direct or indirect [27].

The purpose of this work was to build an active, indirect, environmentally friendly, portable, and low-cost solar dryer for whole or sliced agricultural goods. The drying process starts with the selection, cleaning, and slicing of the products. Depending on the type of fruit or vegetable, some pretreatments can be done prior to dehydration. To inactivate the browning enzymes and keep the color and flavor, one can blanch the products by dipping them in lemon juice or in a supersaturated sugar solution [28]. The temperature must always be kept under 65 °C to avoid deterioration of physical and organoleptic properties.

Many studies focus on different kind of dryers, temperature, and drying time, but there is a lack of studies about drying chamber dynamics and comparative kinetics between different products [20,23]. Furthermore, there is a need to compare solar dryers and commercial electric dryers to understand the advantages and disadvantages of the different types, in particular the associated costs.

This study proposes a new life for fresh products that would be discarded for consumption in nature, allowing their conservation. Their organoleptic and nutritional parameters are kept thanks to the control of temperature that is achieved through the fans that regulate the airflow. Giving a new value to these products, the utilization of solar energy and the reuse of solid waste, like cans and styrofoam boxes, as prototype components brings together, in a single device, the possibility of increasing our ecological footprint.

We had a goal of providing an accessible device with proven effectiveness. Its simplicity should allow it to be used by everybody anywhere, for short periods of time, in a clean and cheap way, avoiding the waste of precious fresh products, while maintaining their color, flavor and nutrients [29].

2. Materials and Methods

For this work two solar and one electrical commercial dryers were used so drying results could be compared. Several experiments were conducted to characterize the drying systems, using sensors to follow the drying process.

2.1. Dryers

Underlying the construction of the solar dryer were such concerns as keeping production costs low and reusing materials, besides making the dryer affordable and portable according to a logic of simple operation and high energy efficiency.

Two different prototypes of solar dryers were then constructed. The first was based on MDF panels (medium-density fiberboard composed of hardwood and softwood residuals combined with wax and resin heat pressed) and the second was based on recycled styrofoam boxes. In both cases, the solar energy heats recycled aluminum cans that have been previously black matte spray painted. The energy is transferred to the air that circulates inside the cans by way of fans that heat the air. This hot air enters the drying chamber to dry the fresh products.

2.1.1. Solar Dryer—Prototype 1

Prototype 1 consisted of a solar collector (57 × 86 cm^2) assembled on the top of a drying chamber, with a tilt of 20°, as illustrated in Figure 1a. The solar collector had three fans of 12 V to force the flow of air through the aluminum cans, perforated and painted black, introducing the hot air into the dehydration chamber below. To reduce the convective losses, the collector top had a 4 mm window glass. The drying chamber had several plastic sliding trays with different mesh sizes that were adjustable to the kind of product we wanted to dry (Figure 1b). The base of the stand was equipped with swivel wheels to provide portability. One ventilation fan was located inside to distribute the hot air to the all-drying chamber, avoiding hot or cold spots. A 100 W photovoltaic panel provided energy to the fans and data acquisition system.

(**a**) (**b**)

Figure 1. Prototype 1: (**a**) solar panel made with MDF wood and aluminum recycled cans. We can see the three fans, one at the top pulling air towards the aluminum cans and two at the bottom directing air to the drying chamber below. (**b**) Dryer chamber with apple slices in trays during dehydration process.

After successful drying tests, we decided to construct Prototype 2, even more compact and with more recycled components.

2.1.2. Solar Dryer—Prototype 2

The Prototype 2 was constructed using recycled styrofoam boxes and consisted of a solar collector (35 × 57 cm^2) mounted on the top of a drying chamber, with a tilt of 12° (Figure 2a,b). The solar collector had 2 fans of 12 V to force the flow of air through the aluminum cans, perforated and painted black, introducing the hot air into the dehydration chamber below. The collector top had a 4 mm window glass. The drying chamber had three plastic trays (Figure 2c) that could be easily removed from the top to load or unload the drying products, and one ventilation fan to distribute the hot air to the entire drying chamber, avoiding hot or cold spots. A 10 W photovoltaic panel provided energy to the fans (Figure 2b). The power to the data acquisition system, when needed, was supplied by the 100 W photovoltaic panel.

(**a**) (**b**) (**c**)

Figure 2. (**a**) Scheme of Prototype 2; (**b**) Solar panel and drying chamber made of styrofoam and aluminum cans; (**c**) drying chamber tray with sliced apples.

2.1.3. Electric Commercial Dryer

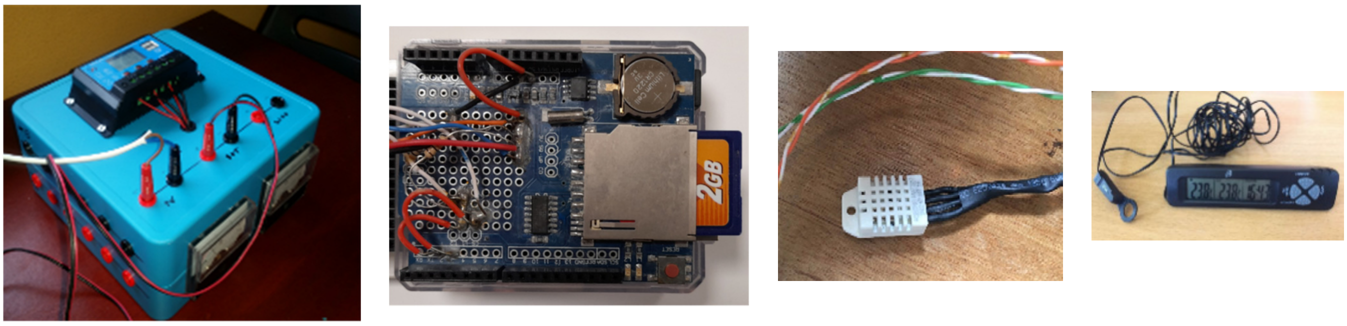
An electric commercial dryer, VidaXL Food Dehydrator with 10 trays, 550 W, adjustable temperature from 40–70 °C (Figure 3a), was used to compare results. We added two Elitech® GSP-6 temperature and humidity data loggers to monitor the bottom and top of the dryer (Figure 3b). Electricity consumption was measured using a Power Meter, Energenie ENER007.

(**a**) (**b**)

Figure 3. (**a**) Electric commercial dryer; (**b**) data loggers.

2.2. Data Acquisition Systems

The 100 W photovoltaic panel was connected to a 12 V 65 Ah battery through a solar charge controller (Figure 4a). This system can feed up to six fans at the same time. The 5 V USB type output of this charge controller feeds an Arduino system (Figure 4b) that registers the inside and outside relative humidity (RH) and temperature from the sensors (Figure 4c). The inside and outside temperature were also measured with a thermometer with an LCD display.



(**a**) (**b**) (**c**) (**d**)

Figure 4. (**a**) Solar charge controller; (**b**) Arduino system; (**c**) Temperature and relative humidity sensor; (**d**) Temperature display. Weight was measured using a Nahita Blue 5162 and a portable Kern EMB 200-3 scales.

To calculate the solar panel efficiency, we measured the inlet air velocity profile with an ACCUSENSE UAS1000 sensor and computed the solar panel power from the air flow and inside and outside air temperatures from Equation (1).

$$\textbf{Panel power} = \dot{m}c_{p_{air}}(T_{in} - T_{out}) \tag{1}$$

where $\dot{m}$ is the air mass flow, Cp_{air} is the heat capacity of the air and Tin and Tout are the inside and outside temperatures, respectively.

The efficiency of the drying process was evaluated through Equation (2), i.e., the amount of water removed divided by the total amount of water in the sample:

$$\eta = \frac{m_i - m_f}{m_{\mathrm{H_2O}}} \tag{2}$$

where, m_i and m_f are initial and final mass of the product, respectively, divided by the water mass.

3. Dryers Characterization

3.1. Available Solar Energy

To properly design a solar dehydration system, we should calculate the solar zenith angle, θ, at the local time and latitude. The drying tests were performed in June, between 14 h30 and 17 h (GMT), at Lat. N 41.3°; Long. W 7.7°, with the sun at the zenith angle of θ = 50° ± 5. For maximum performance, the tilt angle of flat solar panels is usually around the θ value. However, for tubular panels the absorption of the solar radiation is not so dependent on the incident angle due to the curvature of the tubes. The above reported values for the solar panels tilt angle take into account the required space of the drying chamber underneath, for Prototype 1, and the geometrical restrictions of the recycled styrofoam boxes, for Prototype 2.

The solar constant is 1353 W/m^2 and results of the integration of the solar spectrum outside earth's atmosphere.

The Air Mass (AM) is defined as per [30]:

$$\mathrm{AM} = \frac{1}{\cos\theta} \tag{3}$$

However, due to the curvature of the earth, we must correct the equation to:

$$\mathrm{AM} = \frac{1}{\cos(\theta) + 0.50572(96.07995 - \theta)^{(-1.6364)}} \tag{4}$$

The intensity of the direct component of the solar intensity (ID) can be determined as a function of AM, from Equation (5), that also includes the altitude correction (h):

$$\mathrm{ID} = 1353\left[(1-0.14h)0.7^{\mathrm{AM}^{0.678}} + 0.14h\right] \tag{5}$$

Applying Equations (4) and (5) we obtain AM = 1.36 ± 0.1 and ID = 898 ± 21 W/m^2.

To calculate the yield of the solar panels we have performed an experiment on 9 June at around 15:30 (GMT) by measuring the air flow and the obtained temperatures. After equation 1 was applied, we obtained 361 ± 25 W (82%) and 135 ± 18 W (77%) for Prototypes 1 and 2, respectively.

3.2. Assessment of Dehydrators Dynamics

We tested the commercial model before performing experiments in the solar dryers so that we could later compare results. The apple was chosen as the test food product for experimentation because it is a very common fruit available everywhere throughout the year and apple slices can be dried between morning and afternoon.

We monitored the apple slice weight loss in 24 positions of each of the 5 equidistant trays. Tray 1 was defined as being at the top, and the fan and heat source were at the bottom. Figure 5 shows the trays number 5, 7 and 9, which are closer to the heat source, have a faster dehydration kinetics. During the first hour, the weight was lost very fast, especially in tray 9, and we could see the biggest differences between trays. By the end of the 5th hour, the differences in weight loss between trays were smaller; nevertheless, the apple slices in tray 5 and 7 presented less than 10% of their initial mass and were ready be withdrawn, but the apple slices in the other trays were not. Through this study, we concluded that the drying kinetics of the apple slices depended on their position and care must be taken not to remove undried slices.

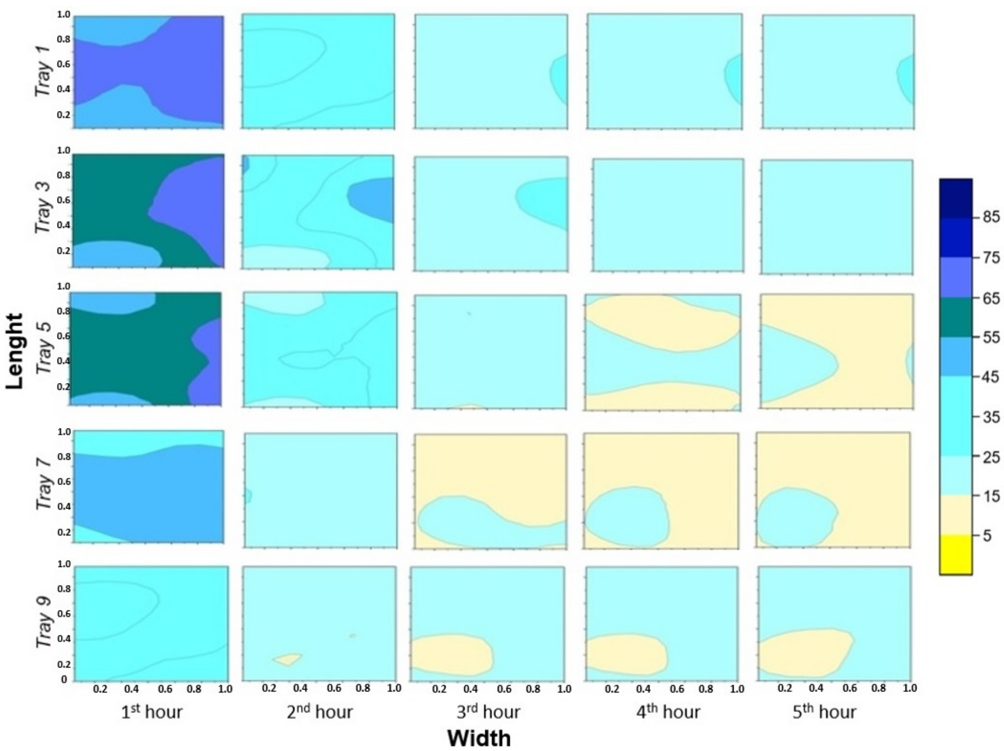


Figure 5. Drying dynamics inside the electric dryer chamber (1–5 h). Tray 9 is located near the bottom heat source. Scale refers to percentage of weight remaining.

A similar study was performed on Prototype 2. We monitored the weight loss in 27 positions for the three trays. In this Prototype the hot air, coming from above, entered one of the sides, and was distributed by the fan of the drying chamber. In Figure 6 we see that the drying process is faster near the fan, but the behavior in the three trays is very similar.

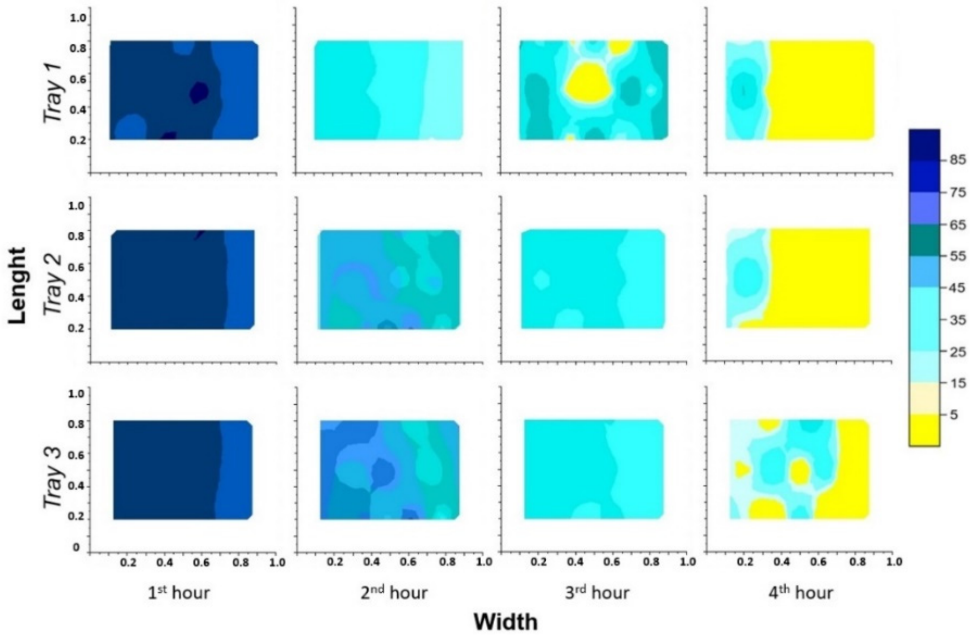


Figure 6. Drying dynamics inside the chamber of Prototype 2 (1–7 h): Tray 1—top, Tray 2—middle, Tray 3—bottom; the scale refers to percentage of weight remaining.

3.3. Solar Fluctuations

It is commonly discussed that one of the major problems concerning solar energy is the fluctuations during the day due to the clouds and through the day and night cycle. To assess this problem, we measured the solar irradiance, the temperature (inside and outside) and the air RH (inside and outside) using Prototype 2 and sliced apples. The results are displayed in Figure 7, where time zero represents the beginning of the experiment at 8:00 (GMT). On the day under consideration, the sky did not present any clouds. The RH of the air entering the drying chamber reached a minimum of 30% around 8–9 h (16:00–17:00 GMT). At almost the same time, the temperature inside the chamber reached its maximum of 67 °C. Some oscillations in the temperature that can be seen on the graphic during this period were due to the opening of the chamber to follow the ongoing drying test. The continuous decrease in the RH inside the chamber might be an indication that most of the moisture from the apples had already been removed. At lower moisture content, the water diffusion inside the slices becomes slower, so the drying kinetics also slows down. During the night, the temperature cools to 15 °C and the RH inside the chamber exceeds 75%, leading to the re-hydration of the apple slices.

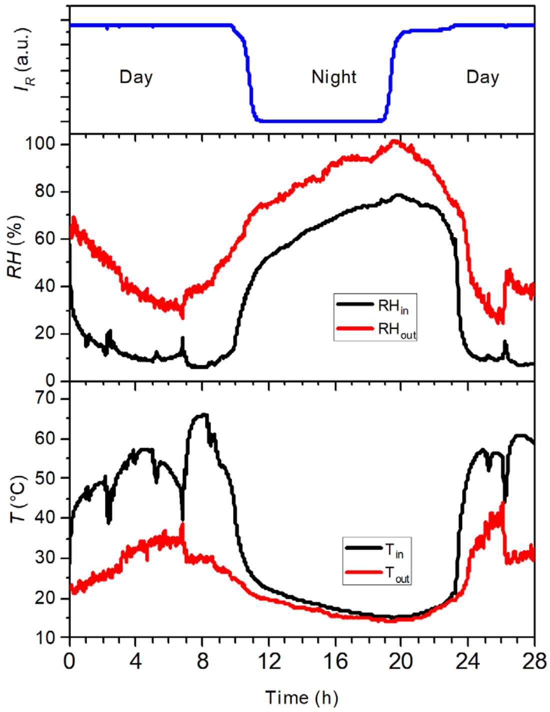


Figure 7. Data acquired by our sensors: periods of day and night, relative humidity and temperature variation over time.

3.4. Comparative Study between Prototype 2 and the Electric Commercial Dryer

To compare the drying kinetics between the solar prototypes and the electric commercial dryer, we chose a sunny day in June to perform an experiment. We had sliced golden-smith apples to the same thickness and distributed them on trays in monolayers. Each tray was weighed at the beginning and at intervals of one hour. The obtained results, in terms of comparison between our prototypes and the electric commercial dryer, are shown in Figure 8. The maximum solar radiation registered was around 1002.6 W/m^2, a value that includes a contribution from diffuse radiation. The temperature inside the chamber of the solar prototype was around 60 °C, with a maximum of 67.4 °C. The minimum RH was 9.2% (28.4 °C and 41.7% RH outside of the chamber). To compare results, we performed the drying in the electric dryer at 60 °C. We can see in Figure 8b that there were no significant differences in terms of moisture loss over time. At the end of the experiment, after 6 h, the moisture content of the apple slices was almost the same, at around 10%.

The food dehydration rate was not constant throughout the process. As drying progresses under fixed conditions, the removal rate of water decreases [31,32]. This can be seen in Figure 8b), which shows the drying curve for sliced apples. In Prototype 2, in the first 3 h, the apple moisture content goes down to 20%, but it takes another 3 h to achieve 10%. In practice, under normal conditions of operation, i.e., temperatures below 65 °C, zero moisture level is never achieved. The dehydration process can be described by heat and mass transfer models [33]. A sliced food will lose moisture from its surfaces, forming a thick dried layer on the surface with the remaining moisture trapped in the center [34]. A gradient of humidity will be established from the center to both surfaces. As a result, the diffusion of water to the surfaces is the limiting step of the drying process. However, the precise shape of a normal drying curve depends on the food, the type of dryer, and drying conditions such as temperature, humidity, speed and direction of air, and food thickness, among other factors [35,36].

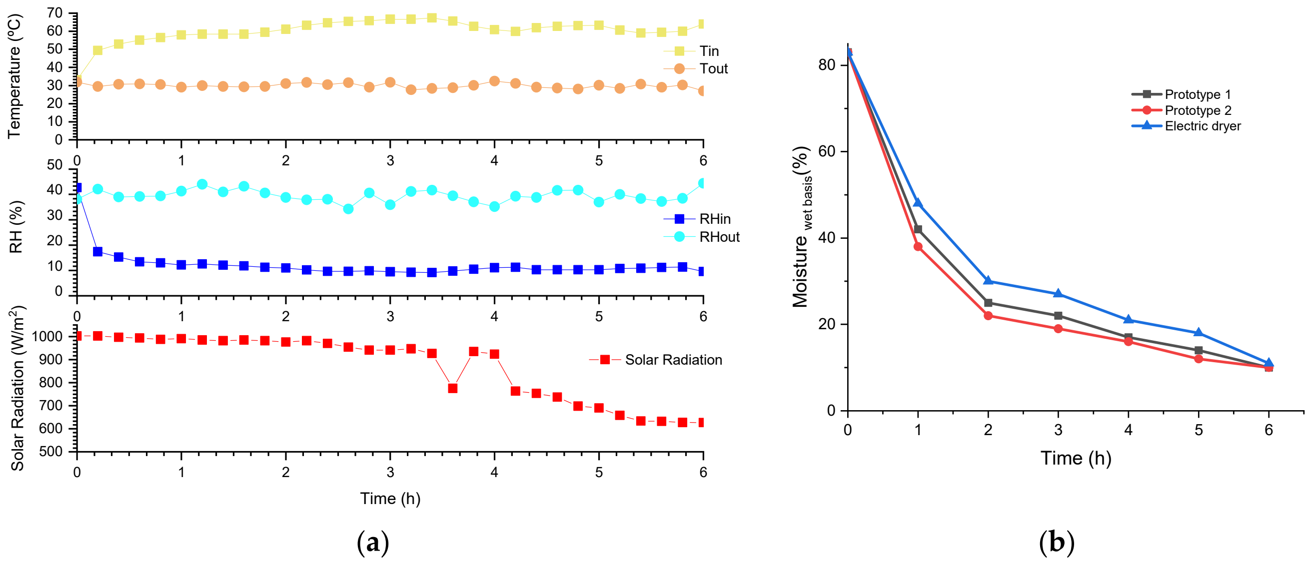


Figure 8. (**a**) Time evolution of the measured solar radiation, temperature, and RH (inlet and outlet) of a representative day of solar drying; (**b**) Comparison of moisture loss, in a wet basis, of apple slices, in an electric dryer and in our prototypes on the same day of (**a**).

4. Drying Tests

Tests were made with sliced golden-smith apple, white mushrooms, zucchini, lemon peel, sweet potatoes, bananas, quarters of tomato, and whole blueberries. Previous tests showed that sliced samples can be dehydrated between morning and afternoon, but whole samples like blueberries can take several days to dehydrate below 10% of water content.

The selected products to be dried had a bright color and characteristic smell, a firm texture, and the absence of macro and microbial injuries, physical damage, eggs, insects, and larvae, indicating suitability for fresh consumption or use in the food industry, considering the physical and sensorial attributes evaluated. Nevertheless, the goal of these solar food dryers was the use of non-marketable fruit, either due to excess production or because it does not have the size and appearance characteristics required by consumers [37].

The standard samples' preparation starts with product selection, washing, removing the core (in apples), cutting in a mechanical slicer to assure the same thickness and weight. Empty trays were weighed at the beginning of each drying operation. The samples were distributed uniformly on the trays in a monolayer. During drying, the trays were regularly unloaded and weighed until the end of the drying process. Inside and outside temperatures and RHs were monitored. The drying was stopped when the residual mass was below 5% on a wet basis. The samples were packed and sealed with a vacuum machine and stored.

Using Prototype 2, we conducted several tests with eight different products. Figure 9 shows the experimental drying curves expressed by an evaluation of the products' moisture content during the drying. The nature of the product and the initial moisture content conditioned the drying kinetics and the value of the residual moisture reached. Sliced products such as apples, mushrooms, zucchini, lemon peel, sweet potatoes, and bananas can be dried below 10% of water content in less than 6 h, meaning that only one drying day is needed. Tomato quarters need at least two days of drying, and whole blueberries can take several days due to the hard serous peel that surrounds the fruits.

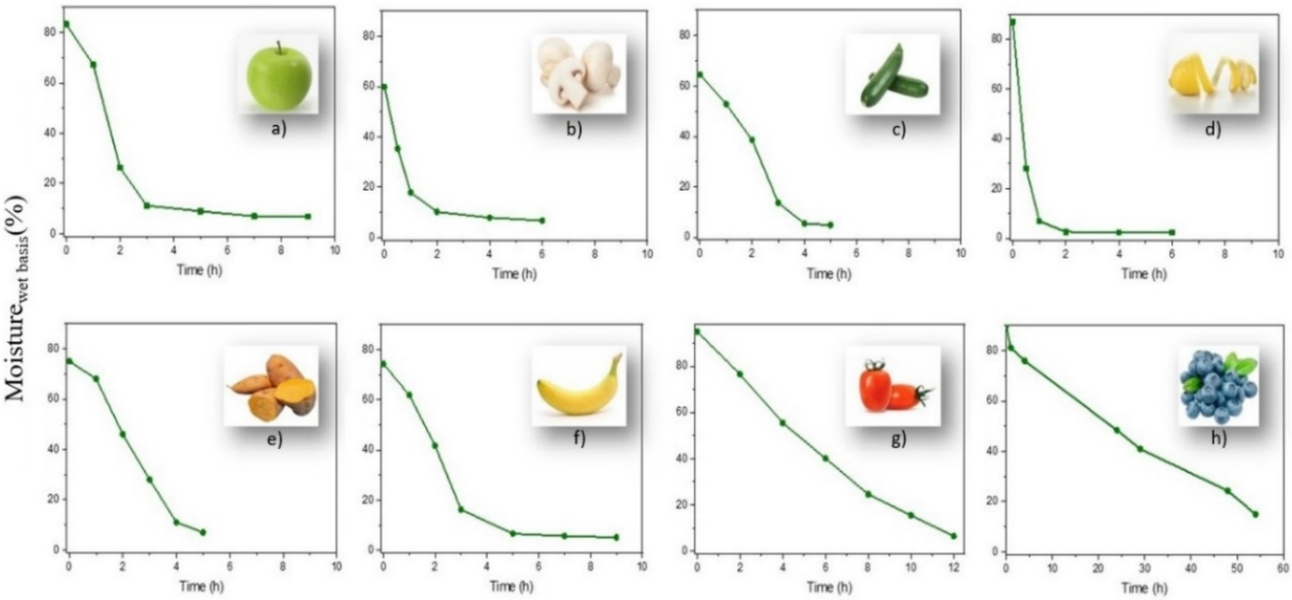


Figure 9. Drying curves (wet basis) of (**a**) apples, (**b**) mushrooms, (**c**) zucchinis, (**d**) lemon peel, (**e**) sweet potatoes, (**f**) bananas, (**g**) tomatoes, (**h**) blueberries.

After applying Equation (2), we get that the yield of the drying process is 95.7% and 95.0% for Prototypes 1 and 2, respectively.

5. Economic Analysis

To assess the economic impact, we performed some calculations. First, we considered the fixed costs of the acquisition of the electric dryer and the components needed for the construction of the prototypes. Then we considered the running costs of the electricity for the electric dryer.

The electric commercial dryer had an acquisition cost of 163 € and had a capacity of around 1.5 kg/batch We considered a reintegration time of 5 years with 60 runs per year. For Prototype 1, all components and raw materials (wood, fans, net, tray sliders, glass, wheels, paint, and glue) had a cost of around 120 € and had a capacity of 4 kg/batch. We considered a utilization time of 4 years with 50 runs/year. For Prototype 2, all components and raw materials (fans, net, tray supports, glass, paint, and glue) had a cost of 40 € and had a capacity of 2 kg/batch. We considered a utilization time of 3 years (it was made of styrofoam) with 40 runs/year. For these two prototypes, there was a need of a 10 W photovoltaic panel to ensure the power for the fans that cost around 22 €.

In terms of the running costs of electricity, we measured in the electric dryer a consumption of 2.67 kWh in a drying experiment of 8 h. In Portugal, the official conversion values for domestic users were 0.18 €/kWh and 0.487 kg CO_2e/kWh (APA; Associação Portuguesa do Ambiente), which means a cost of 0.48 € and an emission of 1.3 kg of CO_2.

We added the fixed costs to the running costs and divided them by the dry weight obtained in each run. We calculated two costs (with and without apple cost), taking into account a small producer that wants to take advantage of excess home production, avoiding waste. The cost of apple slices including acquisition, can be compared to the price of commercial dehydrated apples, with medium price of 0.69 € for 20 g/pack, i.e., 34.50 €/kg dry. The summary of these calculations can be seen in Table 1:

Table 1. Comparative costs of drying apple slices with commercial electrical dryer and solar prototypes.

		Electric Dryer	**Prototype 1**	**Prototype 2**
Acquisition	(€)	163	142	62
Reintegration time	(years)	5	4	3
Number of runs/year	(n)	60	50	40
Loading capacity	(kg)	1.50	4	2
Energy/batch 8 h	(kWh)	2.67	0	0
Energy cost/batch 8 h	(€/kWh)	0.481	0	0
CO_2e/batch 8 h	(kg)	1.30	0	0
Weight of dried product	(kg)	0.150	0.400	0.300
Cost of dry apple slices without purchase the fruit	(€/kg dry)	6.83	1.78	1.72
Apple cost	(€/kg)	1.50	1.50	1.50
Cost of dry apple slices including purchase the fruit	(€/kg dry)	21.83	16.78	16.72

6. Final Remarks and Conclusions

The diverse changes that society has endured have led to the transformation of forms of production and consumption. Environmental issues have taken center stage in scientific debates because they have become threats to the quality of life on the planet because of human actions [38].

Several solar dehydrator designs are available in the market and some of these require expensive materials, which makes them difficult to obtain for small producers [39]. Solar dryers are generally low-cost because they are made of locally available materials with simple construction [40]. In addition, the energy required to dry food is less that needed to freeze or can food, which mitigates consumption of conventional sources of energy, allowing the reduction of CO_2 emissions [41].

Two efficient and economic solar dryers for drying vegetables and fruits were designed and developed. They were tested to demonstrate the proper functioning of all their components. The dehydration of products below 10% of water content was achieved, validated by the dehydration curves and temperature/RH monitoring. Prototypes 1 and 2 were technologically functional, low-cost, and effective in reducing the moisture content of the evaluated samples. Understanding the kinetics of fruit dehydration is critical for optimizing such drying processes and obtaining high-quality dried products [29].

The association with aluminum cans and other recycled materials makes the process more costly and environmentally friendly, avoiding improper disposal of waste. Despite their many advantages, solar dryers have some limitations that influence their performance and negatively affect the drying rate, specifically, the fact that their use is exclusively limited to the daytime period and only if there is sufficient solar radiation.

The use of solar drying for agricultural products has a large potential from the technical and energy-saving point of view. Dehydration is a key technology to preserve fresh fruits in rural areas and thereby reduce food waste. The solar dryer can reduce production costs, energy consumption, and waste (using fruits outside the quality standard for fresh consumption) and is an alternative for small and medium producers.

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