

# Development of a portable solar food dehydrator for drying apricots

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**Abstract:** The present study was conducted in order to design and test a portable solar food dehydrator for drying apricots. Furthermore, in comparison with an electric dehydrator, the solar dryer is in the pyramid shape that consists of a wooden base, a filter to purify the air inside the dryer, iron barriers to fix 4 gray transparent Lyxan polycarbonate with a food grade gray silicon frame to absorb heat, double-wall made of transparent Lyxan polycarbonates with black thermal insulation that placed in between a wooden head fixed to it. From above, carrying a fan with a solar cell to operate the fan during the day. On the sides of the dryer, there are two ventilation openings with a filter to purify the air inside the dryer and two food trays with a wooden frame encasing black perforated plastic polypropylene, which can withstand high temperatures and is safe for food. It does not react or stick to dried food. A black solar collector and a thermal light provide heat during the night, and the thermostat controls the temperature to 57°C inside the dryer, and 150 W generator for powering the heat source charged by a 100 W Solar cell. The results showed when drying the apricots, the temperature inside the solar dehydrator reached 60°C in comparison with the temperature outside the dryer, which reached 38.55°C. In other words, there were differences of 21.45°C between the temperatures inside and outside the dryer when drying apricots. When the drying time increased, the air relative humidity decreased. The rate of decrease in air relative humidity was higher inside the dryer than outside it. As the relative humidity reached 10% inside the dryer when drying apricots at the end of the experiment. As compared with the relative humidity percentages outside the dryer which were 31.32% when dried apricots with differences of 21.32% in relative air humidity inside and outside the dryer, when drying the apricot.

**Keywords:** smart solar dryer, electric dehydrator, compare between electric & solar dryer, dried apricots.

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## 1 Introduction

Many methods have been used for preserving foods, including drying by exposing foods to direct sunlight. However, the disadvantage of this method is that foods are exposed to pollution with dirt and germs, and can also be attacked by insects and rodents. Solar energy is one of the most important sources of

renewable energy that can be used in many things such as solar heaters, solar cookers, street lighting, water desalination, and drying food through direct, indirect or mixed solar dryers. Drying food through solar dryers is one of the important ways to maintain nutrient properties of dried foods. The shelf life of fruits and vegetables must be extended while maintaining their quality for a long time by using solar dryers, canning,

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or freezing (Rehman et al., 2023). Invention of solar dryers made of environmentally friendly materials protect dried foods from contamination and speed up drying time (Awady et al., 2015). The solar collector inside the solar dryer heats the air inside the dryer. This hot air rises onto the dryer trays and heats the food on the dryer trays and the moisture evaporates out of the dryer (Manrique et al., 2020; Srivastava and Shukla, 2017). This process reduced the weight of the dried food by reducing the moisture content (Fortunatus et al., 2017). There are different types of solar dryers including direct, indirect, mixed dryers, and heat source dryers (Mohana et al., 2020). One of the advantages of the heat source dryer is that its performance is better than that of dryers without a heat source (Kumar et al., 2019). There is a study found that dryers with a heat source retain more heat than dryers without a heat source (Rezaie et al., 2017). Apricots are a nutrient-rich food. When processed without the use of sulfur dioxide, they are increasingly appealing to consumers (Baccichet et al., 2024). Drying is continuous, efficient, and independent of solar energy when there is a heat source (Sharma et al., 2009). In Cairo, Egypt, the highest solar radiation in July, 2014 was  $900 \text{ W m}^{-2}$  at 1 pm, and the lowest solar radiation was  $368 \text{ W m}^{-2}$  at 6 pm in summer before sunset (Sida, 2016).

Therefore, it has become necessary to invent new dryers to reach the highest quality of dried food that can be recovered at any time to meet human nutritional needs.

## 2 Materials and methods

### 2.1 Materials

#### 2.1.1 Solar food dehydrator

The solar dryer is in a pyramid shape that consists of a wooden base. Its dimensions are  $45 \text{ cm} \times 45 \text{ cm}$  with four wheels to it, a filter to purify the air inside the dryer, iron barriers to fix 4 grey transparent Lyxan polycarbonate with a food grade grey silicon frame that mixed with ground black seed to give the transparent silicone heat absorption to absorb heat. A  $26.5 \times 26.5 \text{ cm}$  double-wall made of transparent Lyxan

polycarbonate with black thermal insulation was placed in between. A wooden head is fixed to it. From above, carrying a fan with a solar cell to operate the fan during the day. The diameter of the fan is 23.5 cm. On the sides of the dryer there are two ventilation holes with a filter to purify the air inside the dryer and two food trays, the small tray dimensions is  $30.3 \times 30.0 \text{ cm}$  and the big tray dimensions is  $35 \times 35.5 \text{ cm}$ . When using the solar dryer without the heat source, it is able to extend the trays to one more black tray, with dimensions of  $38.5 \times 25.5 \text{ cm}$ , inside the solar dehydrator. The dryer includes trays with a wooden frame encasing black perforated plastic polypropylene, which can withstand high temperature and is safe for food as it does not react or stick to dried food. It also includes a black solar collector, a thermal light to provide heat during the night, a thermostat to control temperature to  $57^\circ\text{C}$  inside the dryer, and a 150 W generator for powering the heat source, which is charged by a 100 W Solar cell.

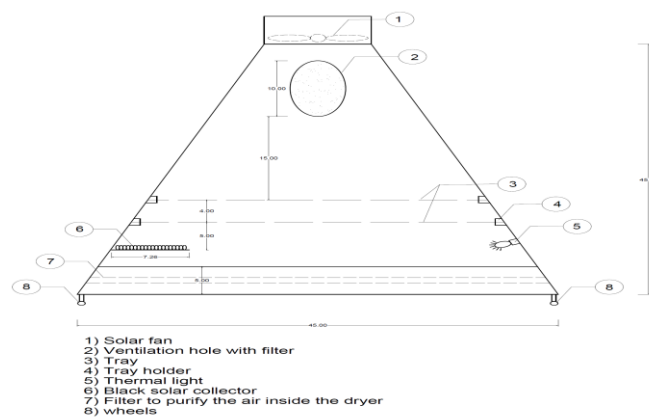


Figure 1 Front and side view of the portable solar food dehydrator with the solar fan



Figure 2 The portable solar dehydrator with the solar fan and the generator.

#### 2.1.2 Traditional method

Local apricots and local pumpkins were washed with cold water, soaked in hot water for 3 minutes, then iced for 3 minutes, and placed in honey.

### 2.1.3 Instrumentation

#### 2.1.3.1 Digital thermometer and hygrometer :

The Sensor Push HT1 is a smart sensor for measuring humidity, temperature, dew point, and vapour pressure deficit (VPD). Its dimensions are 1.57 cm × 1.65 cm. It works with a mobile app that offers unlimited data storage. Data can be graphed within the app or easily exported to Excel. It is used to measure temperature within the range of 20°C to 60°C ±0.3°C / ±0.6°F. It has a wireless range of 100 meters. It is used to measure the maximum and minimum relative humidity of air within the range of 20% – 80% RH.

#### 2.1.3.2 Anemometer

Aoputriver 856A anemometer measures the air velocity within the range of 0.3–45 m s<sup>-1</sup> with accuracy of temperature ±5°C, temperature range 0–45°C, wind flow range 0 – 9999 m<sup>3</sup> min<sup>-1</sup>, wind speed ±( 3% rag +20 dgts) and 600 group data record, The anemometer has a fan which rotates when the air touches it , records air speed readings on the screen and connect to PC with USB.

#### 2.1.3.3 Pyranometer

The pyranometer (TES- 1333R) measures the solar power radiation with a maximum reading of 9999. Meter dimensions / 110 × 64 w × 34 H (mm). The range of up to 1999 W m<sup>-2</sup> or 634BTU/(ft<sup>2</sup>\*h) within the resolution of 1 W m<sup>-2</sup> and runs on a 9 V battery.

#### 2.1.3.4 Moisture Meter:

The moisture meter (model MC-7828G from OCS.tec) measures 150 mm × 65 mm × 30 mm. It calculates the average moisture content and temperature of dried fruits. The device also has a sensor cup measuring 115 mm × 66 mm × 66 mm.

#### 2.1.3.5 Fruit penetrometer

GY-4 series fruit penetrometer is special for inspecting the hardness of fruits such as apricots, pumpkins, peaches, grapes, strawberries and so on.

#### 2.1.3.6 Solar panel

110 W foldable solar panel, open circuit voltage

22.50 V, maximum power voltage 18 V, short circuit current 6.35 A, maximum power current 6.12 A, net weight 2.4 kg, unfolded dimensions 96 cm × 66 cm with built in charge controller and cooling fan to recharge the portable solar generator to run the heat source inside the dryer.

#### 2.1.3.7 Portable solar generator

A 150 W lithium battery (11.1 V / 13500 mAh) that can be charged by the solar cell charge controller without using inverters, with dimensions of 184.5mm × 109.5mm × 118.5 mm, and weight of 1.3 kg.

#### 2.1.3.8 Refractometer

Hanna HI 96801 refractometer for TSS (Sucrose) measurements, works within the range of 0 to 85% Brix/0 to 80°C, with the resolution of 0.1% Brix /0.1°C, and an accuracy of ±0.2% Brix / ± 0.3°C, Temperature compensation: automatic between 10°C and 40°C, 9 V battery type.

#### 2.1.3.9 Scale

The Etekcity Nutrition smart scale tracks the intake of up to 19 nutrients, and monitors trends, creates daily, weekly and monthly nutrition reports and more by connecting to the Vesync app, Apple Health and Fitbit. Equipped with 4 high-precision sensors, it can weigh food between 3 g to 5000 g, its dimensions are 23.36 cm × 16 cm × 1.52 cm.

#### 2.1.3.10 Thermostat

A remote thermostat control for electric heating and cooling devices, to control the temperature inside the solar food dryer to 57°C when running the heat source.

#### 2.1.3.11 Solar fan

A solar fan is placed at the top of the solar dryer to run the fan during the day.

#### 2.1.3.12 Heat source

50 W ceramic black wavy heat lamp is used during the night by connecting it to a thermostat to maintain the optimum temperature for drying fruits and vegetables at 57°C by connecting it to a 150 W generator charged by a 100 W solar cell. The lamp is used during the day without turning it on, as a solar collector because it is black, corrugated and absorbs

heat.

## 2.2 Methods of measurement

### 2.2.1 Food moisture content

Food moisture content was measured before and after the drying process by placing the sample in the electrical drying oven at a temperature of 60°C until constant weight. The moisture content was determined on both wet and dry masses in accordance with Henderson and Perry (1975) as follows:

$$\text{Moisture content, \%} = \frac{\text{wet mass} - \text{dry mass}}{\text{wet mass}} \times 100$$

(on wet basis) (1)

$$\text{Moisture content, \%} = \frac{\text{wet mass} - \text{dry mass}}{\text{dry mass}} \times 100$$

(on dry basis) (2)

### 2.2.2 The moisture ratio (MR)

The moisture ratios (MR) during the drying experiments were calculated using the following equations:

$$MR = \frac{m - me}{mo - me} = EXP(-kt)$$

(3)

$$MR = \frac{m - me}{mo - me} = e^{(-kt)}$$

(4)

Where,

MR = the moisture ratio (%);

m = moisture content (%);

me = equilibrium moisture content (%);

mo = the initial moisture content (g);

t = drying time (h);

k = Drying rate constant (h<sup>-1</sup>) (Hall, 1980).

### 2.2.3 Drying Constant (K)

According to Hall (1980), the data of moisture ratios were plotted on a semi-logarithmic paper versus drying time and fitted to take the form of a straight line, the slope of the fitted line represents the drying constant (k).

### 2.2.4 Drying Rate

According to Bal et al. (2011) drying rate was calculated using the following equations:

$$D = (M_1 - M_2) / T$$

(5)

Where,

M<sub>1</sub> is the actual weight of the product before drying (g);

M<sub>2</sub> is the final weight of the product after drying (g);

T is the time (h).

### 2.2.5 Solar system drying efficiency:

The solar dryer receives solar radiation and converts it into useful heat to evaporate moisture from agricultural products. The ratio of the useful heat (Q<sub>u</sub>) to the incident radiation (Q<sub>i</sub>) is defined as the efficiency of solar drying system (η<sub>s</sub>). It can be calculated according to Awady et al. (1993) as follows:

$$\eta_s = \frac{Q_u}{Q_i} \times 100$$

(6)

$$Q_u = m_r L + m_p C_p \otimes T$$

(7)

$$Q_i = A_c I_p$$

(8)

Where,

m<sub>r</sub> = Mass of moisture removed (kg);

L = Latent heat of water, taken (539 kCal kg<sup>-1</sup>);

m<sub>p</sub> = Mass of agricultural product (kg);

C<sub>p</sub> = Specific heat of the agricultural product, taken (0.88 for apricot kcal kg<sup>-1</sup> °C<sup>-1</sup>) (The Engineering Tool Box, 2014);

T = Temperature rise of agricultural product, (°C);

A<sub>c</sub> = Area of collector, (m<sup>2</sup>);

I<sub>p</sub> = Solar radiation (W m<sup>-2</sup>).

### 2.2.6 Cost analysis

The operation cost of the best designed dryer was calculated according to a modified form of the equation of Awady (1978). This equation is:

$$C = \left(\frac{P}{H}\right) \left(\frac{1}{y} + \frac{i}{2} + t + m\right) + e + \left(\frac{s}{144}\right)$$

(9)

Where,

C = total hourly cost;

P = initial price or capital of dryer (L.E.);

y = estimated life-expectancy of dryer in years;

H = estimated yearly-operating hours;

i = Interest rate;

t = Taxes and overhead rates;

m = Maintenance and repair ratio to capital

head;

e = electric- energy cost (L.E hr<sup>-1</sup>);

s = monthly salaries;

144 = estimated working hours per month.

### 2.2.7 Chemical analysis

In comparison of absorption, retrieval and W.H.C. measurement (water binding ability) via chemical tests, according to (FAO, 2005), five grams of the dried products were added to 200 ml of distilled water, in a 500 ml flask beaker at 25°C for 24 h. After rehydration, samples were taken out, residual water was removed and adhering water was absorbed carefully with tissue paper and then weighed. The rehydration capacity was calculated as follows:

$$(10) \text{Rehydration Capacity} = \frac{W_r}{W_d}$$

Where,

$W_r$  is the weight after rehydration (kg);

$W_d$  is the weight of dried material (kg).

Percentage of humidity according to Henderson and Perry (1975) and TSS (Total Soluble Solids) via refractometer.

### 2.2.8 Statistical analysis

The results were sorted, classified, and presented in various appropriate forms. Statistical coefficients of correlation were calculated, and an examination of the significance of the plans' experimental coefficients and differentiation was conducted by utilizing the statistical program.

## 3 Results and discussion

### 3.1 Effects of dryer design

#### 3.1.1 Temperature

##### 3.1.1.1 Apricots

It can be seen in Figure 3 the temperature inside the solar food dehydrator was 50°C at the beginning of experiment at 2:30 pm, while the ambient temperature was 34.7°C. After 4 hours, the heat source was turned on by the solar generator, and the thermostat maintained the temperature at 57°C for 4 hours. The temperature then decreased to 50°C after turning off the heat source. Then at 10 am, the temperature increased inside the dryer due to the intensity of solar radiation and the heat insulation inside the solar dehydrator. At the end of the experiment the temperature inside the solar dehydrator increased to 60°C, while the ambient temperature was 38.55°C, and the different between the temperature inside the solar dryer and the ambient temperature was 21.45°C, due to the evaporation of moisture from the dried apricots out of the dehydrator and the thermal insulation inside the solar dehydrator.

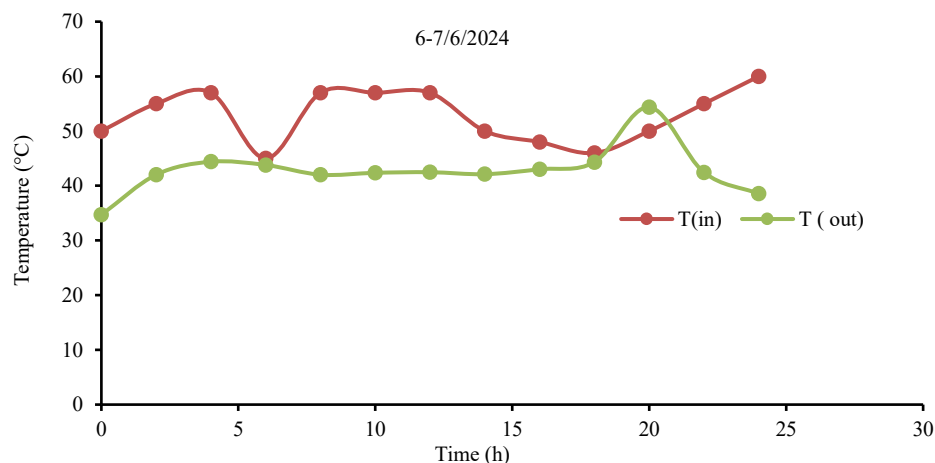


Figure 3 Time and temperature inside & outside the solar food dryer along day hours, when dried apricots, (0 = 2.30 pm)

#### 3.1.2 Relative humidity

##### 3.1.2.1 Apricots

Figure 4 shows the relative air humidity inside the solar food dehydrator. It was 34.47% as compared to the ambient relative humidity was 36.24% at the beginning of the experiment. Then the relative humidity decreased to 15% after 10 hours while the

ambient relative humidity was 49.48 %, this due to the heat source inside the solar dehydrator and the thermal insulation inside the solar dehydrator. After 14 hours, when the heat source was turned off the relative humidity inside the dehydrator increased to 22% as compared to the ambient relative humidity increased to 56.16%, due to the decrease of the temperature inside

and outside the solar dehydrator.

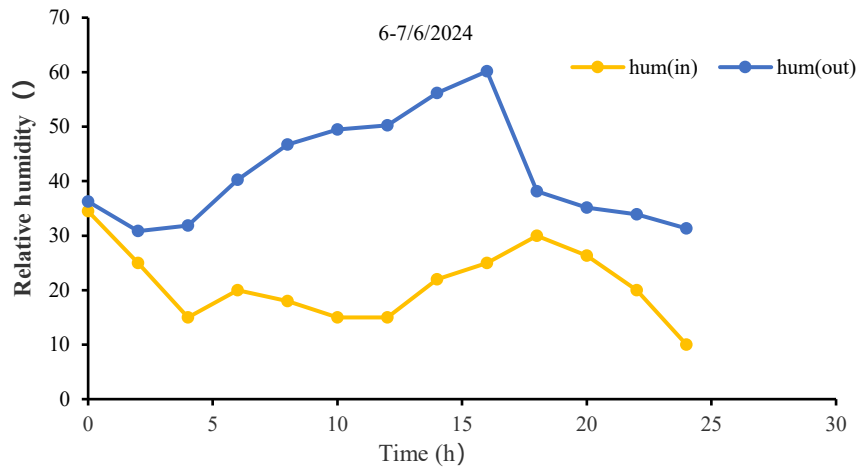


Figure 4 Time and relative humidity inside and outside the solar food dryer along day hours when dried apricots (0 =2.30 pm)

### 3.1.3 Air velocity

It is seen in Figure 5 the maximum air velocity was  $23.55 \text{ m s}^{-1}$  at 4 pm and the minimum air velocity was  $1.02 \text{ m s}^{-1}$  at 10 am in June, 2024 when dried apricots.

It is seen in Figure 6 the maximum air velocity was  $4.5 \text{ m s}^{-1}$  at 12 am and the minimum air velocity was  $1.02$  at 10 am when dried pumpkin in April, 2024.

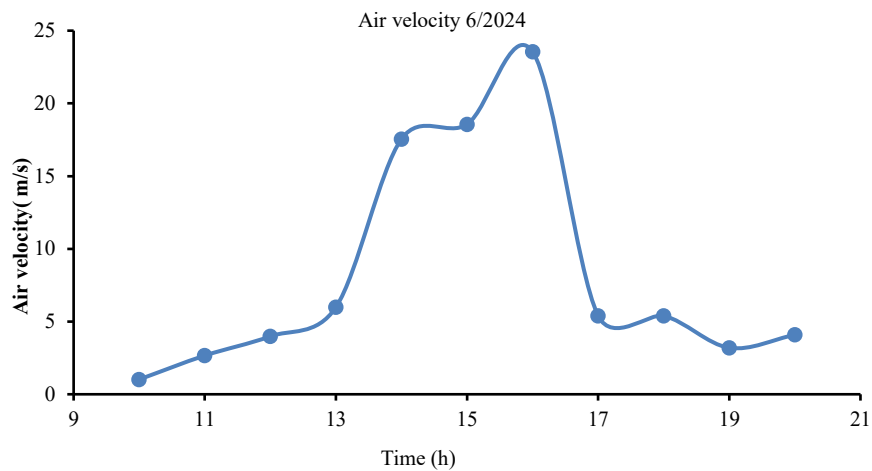


Figure 5 Air velocity ( $\text{m s}^{-1}$ ), and time along day hours when dried apricots (June, 2024)

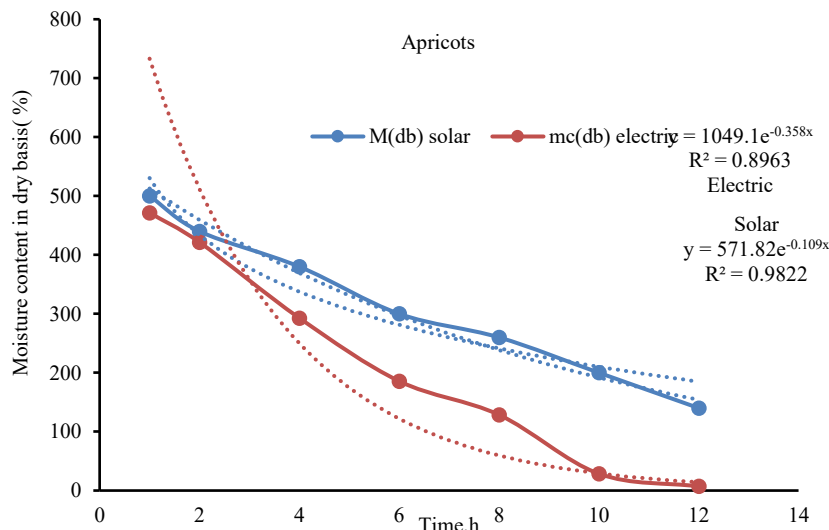


Figure 6 Moisture content on dry basis M.C (db) %, and time along day hours in Apricots & dried by solar food dryer& electric dehydrator (A= Apricots)

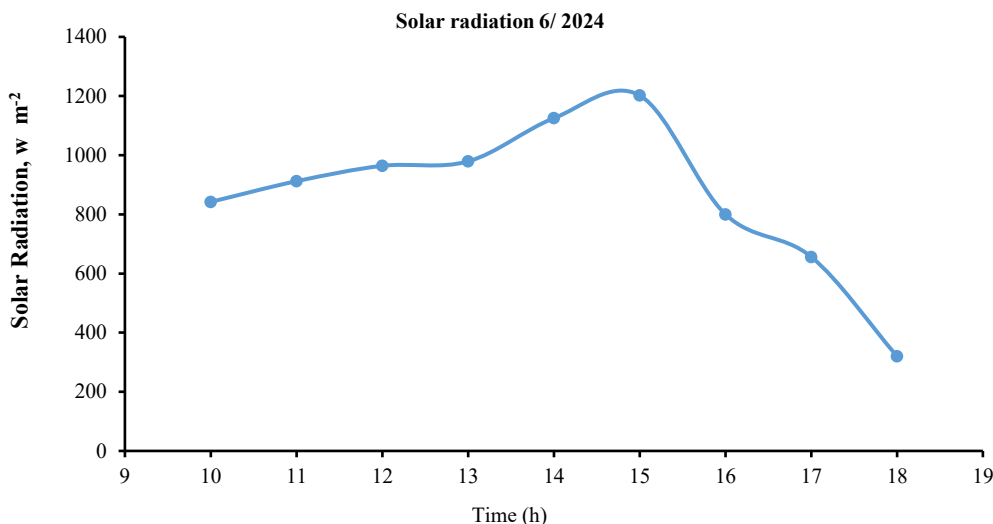


Figure 7 Solar radiation and time along day hours when dried Apricots in Solar food dehydrator (Cairo, Egypt)

3.1.4 Moisture content

For the apricots that was dried by solar food dehydrator, the moisture content in dry, wet basis was 20% and 3.3% respectively at the end of experiment as compared to the moisture content in dry, wet basis when using the electric dehydrator was 7.14% and 1.25% respectively at the end of experiment (Figure 6).

3.1.5 Solar radiation

It is seen in Figure 7 the maximum solar radiation in Cairo, Egypt was 1202 W m<sup>-2</sup> at 15 pm and the minimum solar radiation was 320 W m<sup>-2</sup> at 18 pm (at 06/06/2024) due to approaching sunset.

3.1.6 Solar system drying efficiency

3.1.6.1 Apricots

For the solar food dehydrator in Cairo, Egypt, when drying apricots, the efficiencies of solar drying system ranged between 9.57% at 9 am, 8.08% at 11 am, and 5.21% at the end of experiment.

Solar system drying efficiency tended to decrease as time passed during the early period of drying. This was due to the reduced moisture content in the product. The efficiency remained constant for a while, and then started to increase slightly. This increase may be due to the reduced heat input which is denominator of the efficiency ratio while some heat energy is still stored in the product (Figure 8; The Engineering Tool Box, 2014).

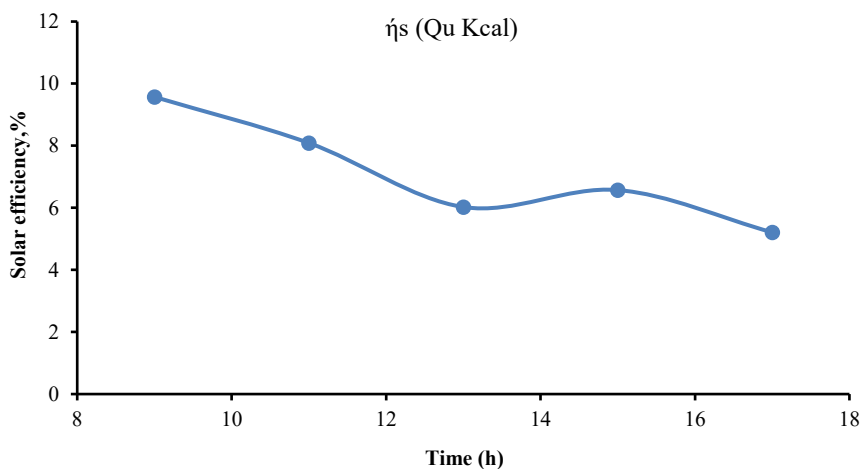


Figure 8 Solar drying system efficiency and time for solar food dehydrator when dried apricots in June, 2024 in Cairo (Egypt)

3.2 Cost analysis

The cost of different dryers were calculated according to equation of Awady (1978) (shown in

chapter of Materials and Methods).

Tables 2 and 3 show the components of the equation, operation cost, capacity, and drying cost per

ton for different investigated drying systems. Drying cost per ton of apricots and pumpkins is 2996 LE ton<sup>-1</sup> for solar food dehydrator and 3138.33 LE ton<sup>-1</sup> for

electric dehydrator respectively.

Capacity increased from 1.5 to 2.75 kg h<sup>-1</sup>, in the solar food dehydrator.

**Table 1 The constants used in Awady equation (Awady, 1978)**

y, years for solar dryer	y, years for electric dryer	H, h year <sup>-1</sup>	i, %	t, %	m, %	e, LE/ 0.05 kW h for solar dryer	e, LE/ 0.055 kW h for electric dehydrator	s, LE Month <sup>-1</sup> hp
25	10	1000	12	5	10	0	0.456	1000 50

Where, y: estimated life-expectancy of dryer in years (assumed), H: estimated yearly-operating hours (assumed), i = investment or overhand rates, m = maintenances and repairs ratio to capital head, hp = power of heat source 50 Watt, kW), e = electric- energy cost (L.E hr<sup>-1</sup>), t = Taxes and overhead rates, and s = monthly salaries (assumed).

**Table 2 values of cost components in Awady equation (Awady, 1978)**

Dryer	P, LE.	C, LE/h.	Capacity, kg h <sup>-1</sup>	Cost, LE Ton <sup>-1</sup>	Cost when drying apricots LE ton <sup>-1</sup>	Number of drying hours (Apricots)
Solar food dryer	2214.408	7.49	2.5	2996	124.83	24
Electric dryer	6500	9.415	3	3138.33	313.83	10

Note: C = total hourly cost and P = initial price or capital of dryer (L.E.).

The dryer size is experimental (small). So, production of the dryer with large number and large scale will cut down the cost to the lowest.

**Cost analysis when drying apricots**

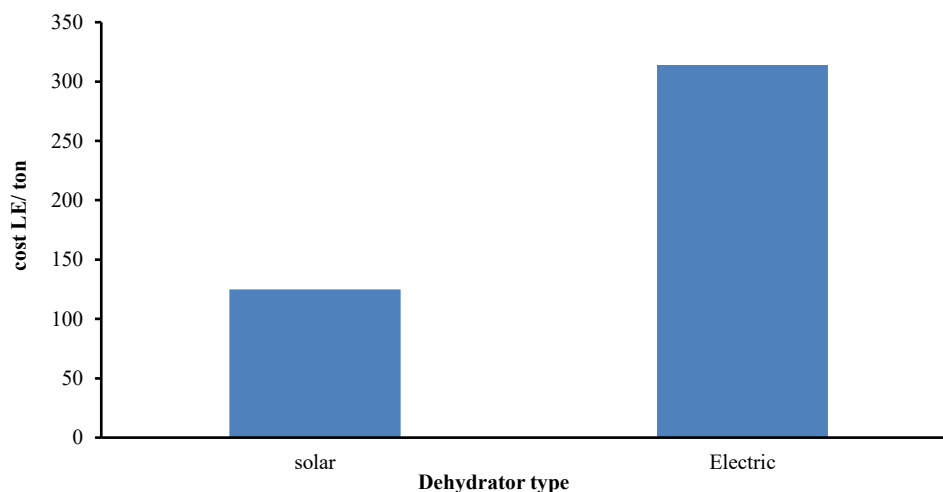


Figure 9 cost analysis for electric dehydrator and solar dehydrator.

### 3.3 Chemical analysis

**Table 3 Percentage of humidity, Rehydration ratio and TSS of Apricots & pumpkin:**

Dryer type	Dried Sample	Percentage of humidity in fresh sample	Percentage of humidity in Dried sample	Rehydration ratio	TSS	Hardness in fresh sample	Hardness in Dried sample
Solar food dehydrator	Apricots	83.2 %	10%	3.2 Kg	19.3 Brix	1.6 Newton	2.54 Newton
Electric dehydrator	Apricots	83.2%	12%	2.8 Kg	17 Brix	1.6 Newton	4.45 Newton

### 3.4 Statistical Analysis

A paired-samples t-test was conducted using SPSS. The results showed that solar radiation intensity had an significant effect on the internal temperature of

the solar food dryer as sig is less than 0.05. Therefore, the hypothesis that the intensity of solar radiation has an effect on the internal temperature is correct (correlation = 0.522).

In the electric dehydrator, moisture content had a significant effect on the rate of weight loss, as sig is less than 0.05. Therefore, the hypothesis that the moisture content has an effect on the rate of weight loss in a dried apricots and pumpkin samples is supported.

#### 4 Summary and conclusion

The present study was conducted in order to design and test a portable solar food dehydrator. The dehydrator is equipped with a 50 W heat and solar fan, a thermostat to control the temperature to 57°C at night, a 150 W generator battery that was charged by a 100 Watt solar cell, which allows the dryer to operate for 3.5 hours before needing a replacement battery. The performance of the solar dehydrator was then compared with that of an electric dehydrator.

The results show that the solar food dryer cost LE 2996, compared to the cost of the electric dehydrator was LE 3138.33. And with electricity, it will cost more due to the electricity fees every month. the maximum temperature inside the solar food dryer reached 60°C, while the ambient temperature reached 38.55°C at the end of the experiment. In comparison, the temperature inside the electric dryer was constant at 57°C.

At the end of the experiment, the relative air humidity inside the solar food dryer was 10% while the ambient relative humidity and electric dryer reached 31.32% and 41.06%, respectively.

At the end of the experiment, for the solar food dryer, the moisture content in dry and wet basis apricots was 20% and 3.3%, respectively, with a drying rate constant (K) of 0.615 h<sup>-1</sup>. For the electric dehydrator, the moisture content on a dry basis and wet basis was 7.14% and 1.25%, respectively, with a K value of 0.404 h<sup>-1</sup>.

The maximum solar radiation in Cairo, Egypt, was 1202 W m<sup>-2</sup> at 3:00 pm and the minimum solar radiation was 320 W m<sup>-2</sup> at 6:00 pm, due to the approaching sunset.

Finally, the solar food dryer operates using a solar fan at day and with 50 W heat source at night. The design combines the characteristics of a solar and electric dehydrator, with produces high-quality dried

foods with lowest possible cost, use clean energy, and can operate in day and night.

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