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Impact of drying temperature, system and product thickness on the pomegranate quality, energy consumption and drying cost

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Abstract

This work focuses on studying the influence of system and drying temperatures on the quality of pomegranate and energy consumption. Drying temperatures that were used 50, 60 and 70 °C for hybrid solar and artificial drying systems. The peel layer thicknesses were 1. 2 and 3 cm. weight loss, moisture loss, drying rate, energy consumption and costs were determined. The results revealed that the drying pomegranate artificially (oven) recorded the highest weight losses (77.72%) at 70 °C compared to the other systems and temperatures. The moisture content of pomegranate peels ranged from 215.10 to 258.68 and 218.88 to 263.75 % d.b. for both solar and artificially drying systems, respectively. The drying rate of pomegranate peels ranged from 60.89 to 135.75 and 61.44 to 136.50 g_{water} kg^{-1} h^{-1} for both hybrid solar and oven drying systems, respectively. Using the oven drying system recorded the highest energy consumption at the lower type, where it recorded 2.12 kW kg^{-1} dried, which in turn recorded the highest cost of 1 kg dried product, where it recorded 13.62 LE kg^{-1} at the same conditions.

Keywords: Pomegranate, Hybrid Solar, Oven drying, moisture level, drying rate, Energy, Cost

Introduction:

The pomegranate (*Punica granatum L.*) is a very important plant, its fruits are consumed, and it has many medical uses. Also, it could be used in the food industry, using their juices **[39]**. Thus, the fruit itself produces three parts: the seeds, which correspond to approximately 3% of the weight of the fruit and consist of approximately 20% oil; the juice, representing about 30% of the weight of the fruit; and the shells (pericarp), which include the inner network of membranes and account for 67% of the total weight **[24]**.

Pomegranate was transferred to the Middle East through the arid and semi-arid area, such as Brazil **[35]**. India, Iran, Afghanistan, Morocco, Spain, Turkey, Tunisia and Egypt that were the main countries that growing and producing pomegranates **[15] and [28]**. The reason behind the arid and semi-arid regions, where water scarcity and salinity are limiting factors. It is used for medicinal treatments of different pathologies **[11]**. The pomegranate has many uses, where the people could use the peels and pulp as well as the flowers, leaves and branches. The extraction of these parts conditions antioxidants, antifungals, and antimicrobial. Also, it could be used for treating the inflammation and proliferation of cancer cells **[25] and [31]**.

The pomegranate peels have high moisture content, which could be reduced to increase their values. The wasks produced from the pomegranate fruits have natural antioxidants such as phenolic acids and flavonoids **[36] and [26].**

Drying is a process to reduce moisture to preserve and prolong the shelf life of different food products **[32]**. It aims to increase the solid to a level that decreases the microbial activities and deterioration chemical reactions **[22], [33] ,[37] and [8]**. The drying inhibits the activities of microorganisms and enzymes, which enable the produce to be stored longer **[4]**. In general, drying is a thermal process that causes the water to evaporate from the phytochemical changes and affects the quality properties like texture, colour and nutritional values **[27], [6] and [10]**. Several drying techniques used for various products include air, oven and freeze drying. Generally, air-drying and oven drying are favoured due to processing cost and efficiency **[38]**.

The pomegranate peels have a higher content of antioxidants, which is very effective in protecting cells from oxidative stress. Also, the antioxidant activity could help in reducing the risk of chronic diseases and reduce the aging process **[3].** Pomegranate peels also contain anti-inflammatory components, which help in decreasing the inflammation-related conditions **[7]**. They are also used for their astringent properties to soothe skin conditions like acne and eczema **[9]**. X

Pomegranate peels suffer a great deal of losses in weight and quality during the conventional drying process due to the long period of drying and the high fluctuation in drying conditions. Using direct and indirect solar drying is not sufficient to dry pomegranate peels, therefore, using a hybrid solar drying system is very important to overcome the abovementioned problems. Also, temperature of drying and plant layer thickness are the most important factors affecting the product quality and shelf life after drying, therefore, the main aim of this work is to study the effect of drying system, drying temperature and layer thickness on the drying parameters of pomegranate peels, quality product, energy consumption and drying cost under the hybrid solar drying system.

2. Materials and methods

The experiment was conducted at the Department of Agricultural and Bio-Systems Engineering, Agriculture College, Moshtohor, Benha University, Egypt (latitude 30° 21` N and 31° 13` E). During the season 2024 from September to October. The ambient air temperature ranged from 21.6 to 34.1 ^{o}C, the relative humidity (RH) ranged from 42.6 to 77.3 % and solar radiation ranged from 321.9 to 954.1 kJ m^{-2} day^{-1}.

2.1. Materials

Pomegranate (*Punica granatum L.*) fruits Wonderful varieties were purchased from the local farms at the beginning of the season at moisture content ranging from 75 to 77% (wb)

Drying systems

The pomegranate peel was dried under two drying systems as follows:

2.1.1.1. Hybrid solar drying system

Fig. 1 shows the hybrid solar drying system. The system includes, collector, chamber, trays, blower, heater, and control unit.

Fig. 1 Hybrid solar dryer.

The solar collector

The collector has three parts; the first part is the glass cover with dimensions of 4.0 x 1.0 x 5.0 mm (length, width and thickness). The glass cover is fitted on a frame that made from wood. The collector is divided into lines with 50 cm width. The absorber plate was made from aluminum plate which is insulated using glass wool with a thickness of 5.0 cm as shown in fig 2.

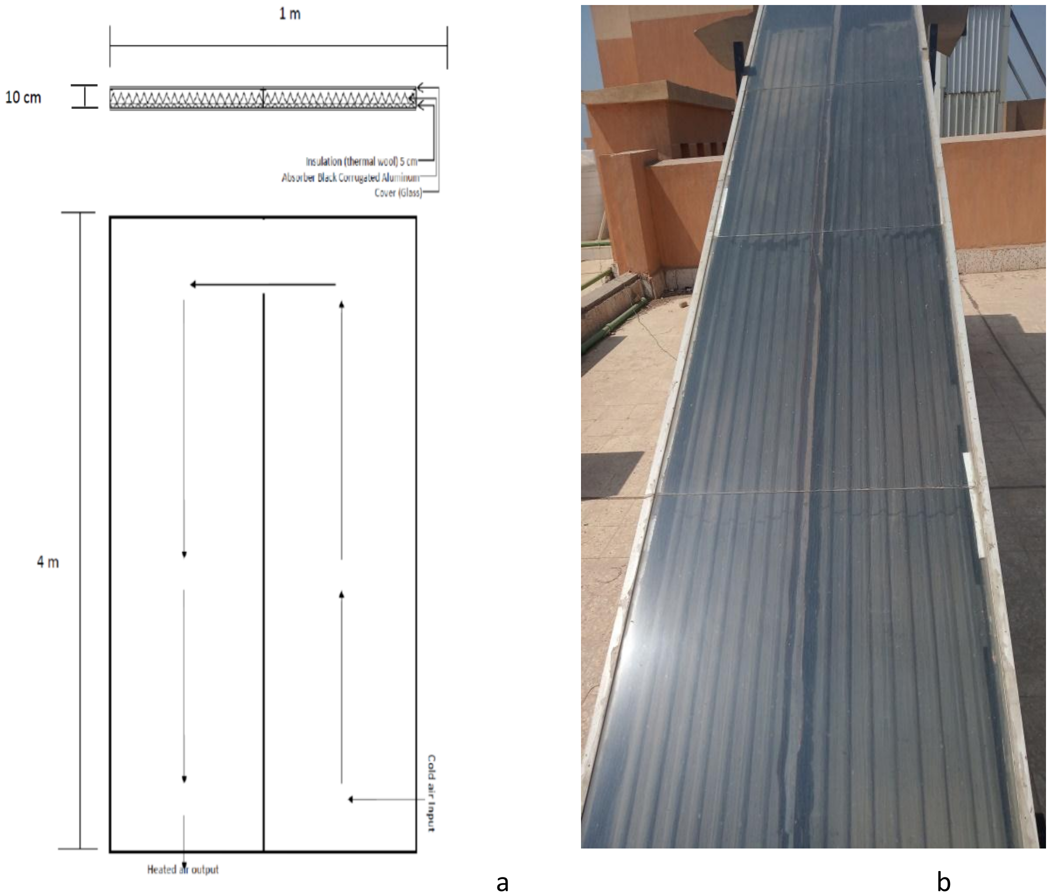

Fig. 2 Solar collector. (a) Geometric view (b) Top view.

Drying chamber

The dimensions of the drying chamber were 1.0 x 1.0 x 1.0 m which is made from galvanized steel with a thickness 5 mm. It is supported on four wheels. The chamber was insulated using glass wool (5 cm thickness) and foam layer (3 cm thickness) as shown fig. 3. The chamber has 6 trays with dimensions of 0.3 x 0.2 x 0.07 m length, width and thickness which are made from stainless steel and cover with perforated sheet. Air will be forced using a blower (Model C.C.P. Parma – Flow Rate 6.6 m^3 h^{-1} – RPM 2800 – Power 150 W, 220V 50Hz, Italy). The trays were loaded inside trolley derived with a motor has a gear box.

Fig. 3. The drying chamber.

Temperature control unit

Digital temperature controller (REX_C100 PID) is used to control the start and stop of the additional heat source (the electric heater 2000 watts) to ensure the stability of the temperature inside the drying room.

Electric heater

An electric heater with a capacity of 2000 watts was used to heat the air inside the drying room as an additional energy source with solar energy.

Control units

To control the temperature and air humidity inside the drying chamber, a digital controller of temperature (REX_C100 PID) was used. Also, an electric heater (2000 watts) was used to raise the temperature inside the drying chamber. Also, to measure the energy consumed in the drying process. Fan speed was also controlled.

Oven drying

Pomegranate peels were spread evenly on baking sheets and placed in a conventional laboratory oven (Fisher Scientific Isotemp Oven, Model 655F Cat. No. 13- 245-655, Fisher Scientific, Toronto, Ontario, Canada).

Methods

2.2.1. Treatments

In this study, the treatments include: two drying systems (hybrid solar and oven systems), drying temperatures (50, 60 and 70 °C) and three thickness layer were (1, 2 and 3 cm).

Measurements and determinations

Drying measurements

The weight of the product was monitored using a digital balance (Model HG – 5000 – Range 0 - 5000 g ± 0.01 g, Japan) each hour for both drying systems. Temperature and relative humidity were measured using a Data logger (Model TH165 – Range -20 to 70 °C and 5 to 95% RH, Australia). The electrical energy was determined by recording the voltage and current of the whole system.

Moisture content

Moisture content of the fresh and dried pomegranate peels were determined using a conventional laboratory oven kept at 105 °C until constant weight was reached according to **[5]**. Triplicate determinations were made, and the moisture content was calculated as the following equation:

$$MC = \frac{M_{wet} - M_{dry}}{M_{dry}} \times 100 \quad (1)$$

Where:

MC refers to the moisture content, % d.b.

M_{wet} is the fresh mass, g

M_{dry} is the final dried mass, g

Drying rate

The rate of drying was determined according to **[14]** as follows:

$$DR = \frac{M_{t+dt} - M_t}{dt} \quad (2)$$

Where:

DR refers to the rate of drying, $kg_{water}/kg_{dry\ base}.hr$

M_t is the moisture content at any time t, % d.b.
M_{t+dt} is the moisture content at t+dt, % d.b.
t is the drying time, (hr)

Power and energy consumption

The power consumption was determined according to the following equation **[23]**:

$$P = \frac{I \times V \times cos\theta}{1000} \quad (3)$$

Where:
P is the power consumed, kW
I is the current, Amps
V is the voltage, volt
cosθ is the power factor being equal to 0.85

Cost calculation for the pomegranate drying

The costs were calculated according to **[19]**. Table 1 shows inputs of drying cost components for dryer operating for pomegranate drying.

Table (1): Cost determination inputs.

Inputs	Cost, LE
Dryer price, LE.	15000
Motor used, kW	1.0
Expected life, year	5
Taxes, %	3
Repair and maintenance, %	10
Interest, %	12
Labors, LE h^{-1}	20

Results and Discussion

Drying conditions (temperature and relative humidity), weight losses, moisture content and drying rate were determined for pomegranate peels as affected by changing drying systems, drying air temperatures and peel layer thicknesses.

3.1. Weight loss of pomegranate peels:

Figs. (4a, b and c) show the accumulated weight losses of pomegranate as affected by drying systems, drying temperature and layer thickness of the pomegranate peels. The results showed that the accumulated weight losses of the pomegranate peels was affected gradually by the drying temperature while, they were affected inversely by the layer thickness, where the results indicate that the weight losses of the pomegranate peels dried under the hybrid solar drying system at 50 ºC recorded an average of 21.43% after hour of drying depending on the layer thicknesses of 1, 2 and 3cm. The weight losses increased gradually with the drying to reach 74.7% after 8 hours for the 1cm layer thickness, while it reached 73.3% after 11 hours for the 2cm layer thickness, and it reached 72.9% after 15 hours for the 3cm layer thickness. For oven drying system, the weight losses of the pomegranate peels dried at 50 ºC recorded an average of 21.67% after one hour drying depending on the layer thicknesses of 1, 2 and 3cm. The weight losses increased gradually with the drying to reach 75.68% after 8 hours for the 1cm layer thickness, while it reached 74.91% after 11 hours for the 2cm layer thickness, and it reached 74.56% after 15 hours for the 3cm layer thickness. The trend of these results agreed with those obtained by **[17] ,[1] and [34]**.

The results also indicate that the weight losses of the pomegranate peels dried under hybrid solar drying system at 60 ºC recorded an average of 26.58% after one hour drying depending on the layer thicknesses of 1, 2 and 3cm for hybrid solar drying system. The weight losses increased gradually with the drying to reach 75.23% after 6 hour for the 1cm layer thickness, while it reached 74.7% after 9 hours for the 2cm layer thickness, and it reached 74.32% after 12 hours for the 3cm layer thickness. For oven drying system, the results also indicate that the weight losses of the pomegranate peels dried at 60 C recorded an average of 27.90% after one hour drying depending on the layer thicknesses of 1, 2 and 3cm for hybrid solar drying system. The weight losses increased gradually with the drying to reach 76.37% after 6 hour for the 1cm layer thickness, while it reached 75.85% after 9 hours for the 2cm layer thickness, and it reached 75.20% after 12 hours for the 3cm layer thickness.

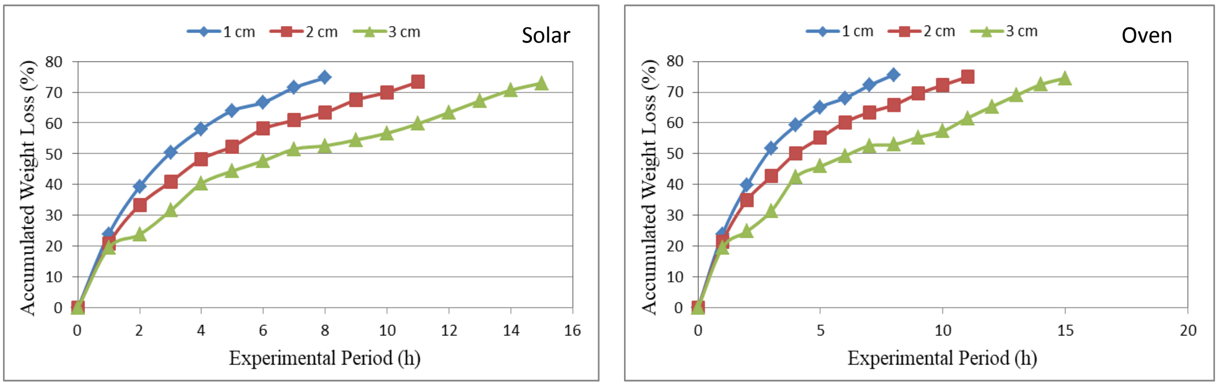

Fig. (4a): The accumulated weight loss of pomegranate peels at 50 °C drying temperature for different drying systems.

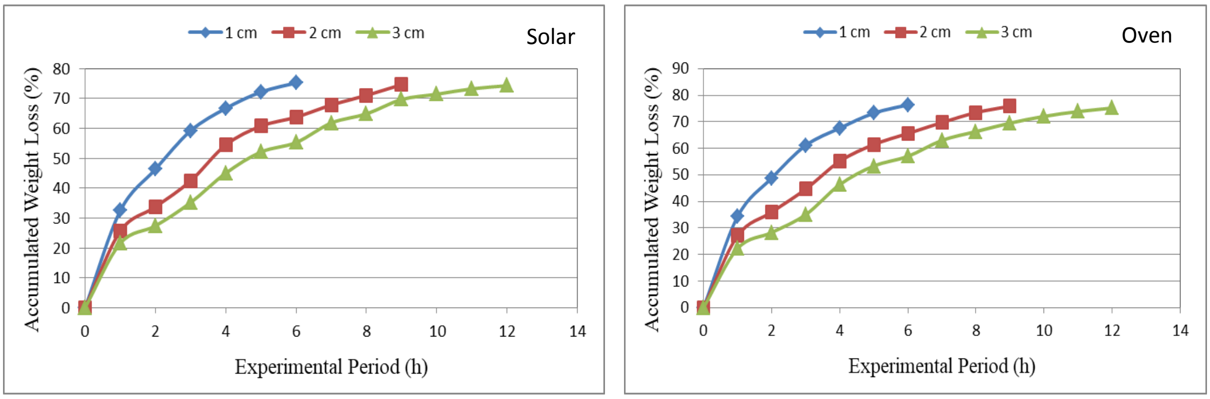

Fig. (4b): The accumulated weight loss of pomegranate peels at 60 °C drying temperature for different drying systems.

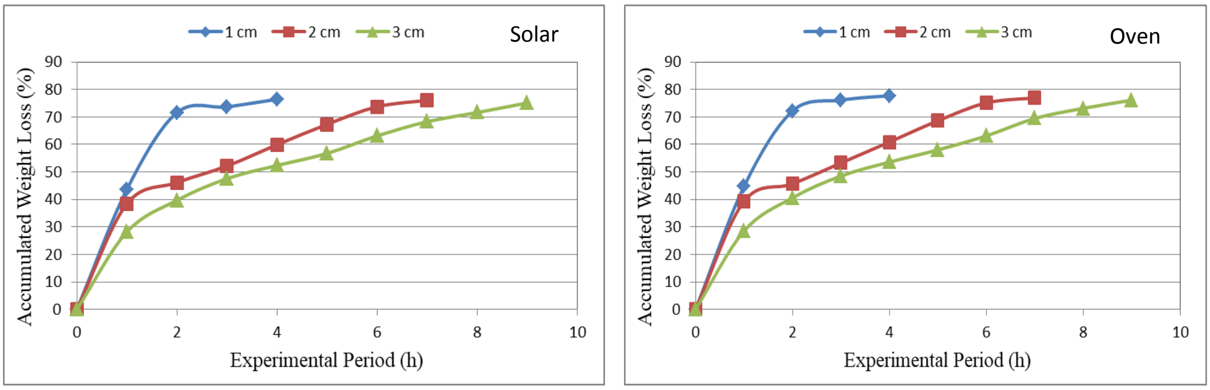

Fig. (4c): The accumulated weight loss of pomegranate peels at 70 °C drying temperature for different drying systems.

The results also indicate that the weight losses of the pomegranate peels dried under the hybrid solar drying system at 70 ºC recorded an average of 36.74% after hour of drying depending on the layer thicknesses of 1, 2 and 3cm. The weight losses increased gradually with the drying to reach 76.44% after 4 hours for the 1cm layer thickness, while it reached 76.02% after 7 hours for the 2cm layer thickness, and it reached 75.11% after 9 hours for the 3cm layer thickness. For oven drying system, the results also indicate that the weight losses of the pomegranate peels dried at 70 ºC recorded an average of 37.48% after one hour drying depending on the layer thicknesses of 1, 2 and 3cm. The weight losses increased gradually with the drying to reach 77.72% after 4 hours for the 1cm layer thickness, while it reached 76.88% after 7 hours for the 2cm layer thickness, and it reached 76.13% after 9 hours for the 3cm layer thickness. These results agreed with those obtained by **[13] and [17]** who found that the accumulated weight loss increases with increasing drying temperature.

3.2. Moisture level of pomegranate peels:

Figs. (5a, b and c) show the moisture level of pomegranate peels affected by drying systems, drying temperature and layer thickness of the pomegranate peels. The results showed that the moisture level of the pomegranate peels was affected gradually by the drying temperature while, it affected inversely by the layer thickness, where the results indicate that the moisture level of the pomegranate peels dried under the hybrid solar drying system at 50 ºC recorded an average of 219.01% after hour of drying depending on the layer thicknesses of 1, 2 and 3cm. The moisture level decreased gradually with the drying to reach 3.27% after 8 hours for the 1cm layer thickness, while it reached 3.43% after 11 hours for the 2cm layer thickness, and it reached 2.34% after 15 hours for the 3cm layer thickness. For the oven drying system, the moisture level of the pomegranate peels dried at 50 ºC recorded an average of 222.58% after hour of drying depending on the layer thicknesses of 1, 2 and 3cm. The moisture level decreased gradually with the drying to reach 3.61% after 8 hours for the 1cm layer thickness, while it reached 2.67% after 11 hours for the 2cm layer thickness, and it reached 2.12% after 15 hours for the 3cm layer thickness. These results agreed with those obtained by **[2]**.

The moisture level of the pomegranate peels dried under hybrid solar drying system at 60 ºC recorded an average of 225.89% after one hour drying depending on the layer thicknesses of 1, 2 and 3cm. The moisture level decreased gradually with the drying to reach 3.13% after 6 hours for the 1cm layer thickness, while it reached 3.73% after 9 hours for the 2cm layer thickness, and it reached 1.06% after 12 hours for the 3cm layer thickness. For oven drying system, the moisture level of the pomegranate peels dried at 60 ºC recorded an average of 229.22% after one hour drying depending on the layer thicknesses of 1, 2 and 3cm. The moisture level decreased gradually with the drying to reach 3.23% after 6 hours for the 1cm layer thickness, while it reached 2.41% after 9 hours for the 2cm layer thickness, and it reached 1.34% after 12 hours for the 3cm layer thickness.

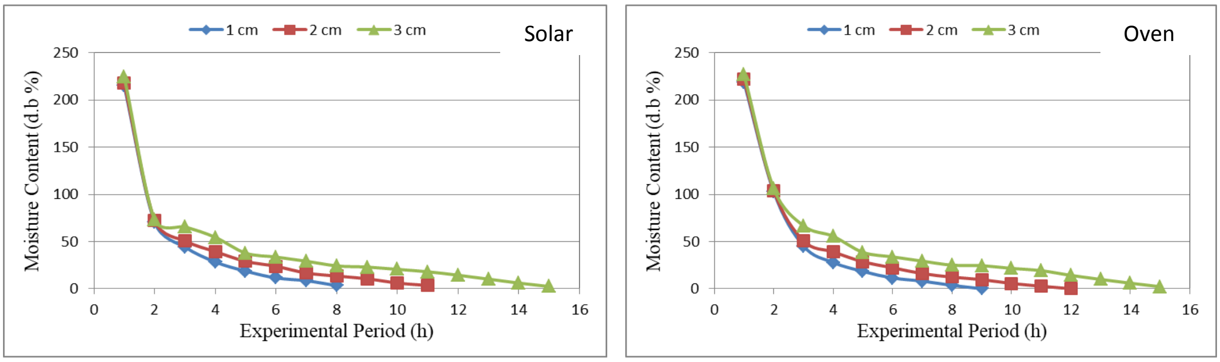

Fig. (5a): The moisture content of pomegranate peels at 50 °C drying temperature for different drying systems.

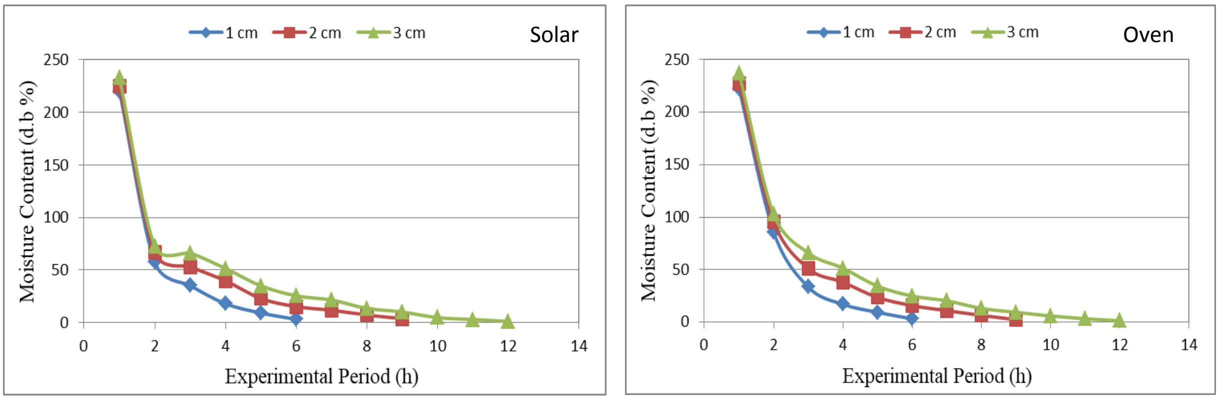

Fig. (5b): The moisture content of pomegranate peels at 60 °C drying temperature for different drying systems.

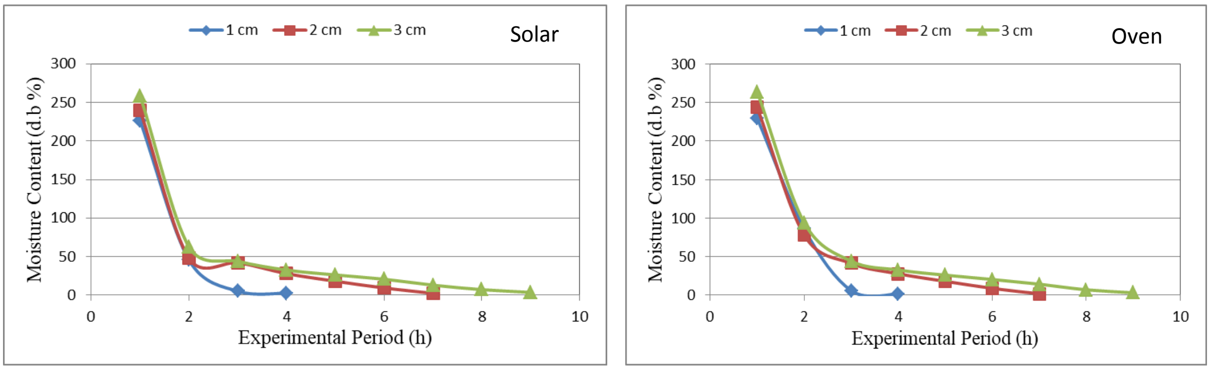

Fig. (5c): The moisture content of pomegranate peels at 70 °C drying temperature for different drying systems.

At 70 °C drying temperature, the moisture level of the pomegranate peels dried under the hybrid solar drying system recorded an average of 241.71% after hour of drying depending on the layer thicknesses of 1, 2 and 3cm. The moisture level decreased gradually with the drying to reach 2.84% after 4 hours for the 1cm layer thickness, while it reached 2.33% after 7 hours for the 2cm layer thickness, and it reached 3.59% after 9 hours for the 3cm layer thickness. For the oven drying system, the moisture level of the pomegranate peels dried at 70 ºC recorded an average of 245.48% after hour of drying depending on the layer thicknesses of 1, 2 and 3cm. The moisture level decreased gradually with the drying to reach 1.62% after 4 hours for the 1cm layer thickness, while it reached 1.77% after 7 hours for the 2cm layer thickness, and it reached 3.07% after 9 hours for the 3cm layer thickness. These results agreed with those obtained by **[12] and [20]** who found that the moisture level increases with increasing drying temperature.

3.3. Drying rate of pomegranate peels:

Figs. (6a, b and c) show the drying rate of pomegranate peels affected by drying systems, drying temperature and layer thickness of the pomegranate peels. The results showed that the drying rate of the pomegranate peels was affected gradually by the drying temperature while, it affected inversely by the layer thickness, where the results indicate that the drying rate of the pomegranate peels dried under the hybrid solar drying system at 50 ºC recorded an average of 51.38 $g_{water}\ kg^{-1}\ h^{-1}$ after hour of drying depending on the layer thicknesses of 1, 2 and 3cm. The drying rate decreased gradually with the drying to reach 11.61 $g_{water}\ kg^{-1}\ h^{-1}$ after 8 hours for the 1cm layer thickness, while it reached 9.11 $g_{water}\ kg^{-1}\ h^{-1}$ after 11 hours for the 2cm layer thickness, and it reached 9.87 $g_{water}\ kg^{-1}\ h^{-1}$ after 15 hours for the 3cm layer thickness. For the oven drying system, the drying rate of the pomegranate peels dried at 50 ºC recorded an average of 51.87 $g_{water}\ kg^{-1}\ h^{-1}$ after hour of drying depending on the layer thicknesses of 1, 2 and 3cm. The drying rate decreased gradually with the drying to reach 8.32 $g_{water}\ kg^{-1}\ h^{-1}$ after 8 hours for the 1cm layer thickness, while it reached 8.58 $g_{water}\ kg^{-1}\ h^{-1}$ after 11 hours for the 2cm layer thickness, and it reached 8.61 $g_{water}\ kg^{-1}\ h^{-1}$ after 15 hours for the 3cm layer thickness.

The results indicate that the drying rate of the pomegranate peels dried under the hybrid solar drying system at 60 ºC recorded an average of 65.70 $g_{water}\ kg^{-1}\ h^{-1}$ after hour of drying depending on the layer thicknesses of 1, 2 and 3cm. The drying rate decreased gradually with the drying to reach 11.00 $g_{water}\ kg^{-1}\ h^{-1}$ after 6 hours for the 1cm layer thickness, while it reached 9.87 $g_{water}\ kg^{-1}\ h^{-1}$ after 9 hours for the 2cm layer thickness, and it reached 9.01 $g_{water}\ kg^{-1}\ h^{-1}$ after 12 hours for the 3cm layer thickness. For the oven drying system, the drying rate of the pomegranate peels dried at 60 ºC recorded an average of 66.62 $g_{water}\ kg^{-1}\ h^{-1}$ after hour of drying depending on the layer thicknesses of 1, 2 and 3cm. The drying rate decreased gradually with the drying to reach 9.37 $g_{water}\ kg^{-1}\ h^{-1}$ after 6 hours for the 1cm layer thickness, while it reached 9.11 $g_{water}\ kg^{-1}\ h^{-1}$ after 9 hours for the 2cm layer thickness, and it reached 5.02 $g_{water}\ kg^{-1}\ h^{-1}$ after 12 hours for the 3cm layer thickness.

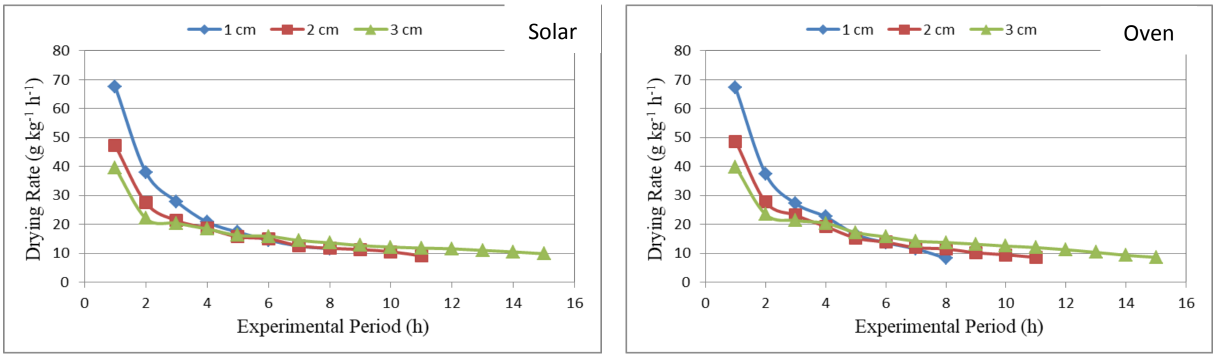

Fig. (6a): The drying rate of pomegranate peels at 50 °C drying temperature for different drying systems.

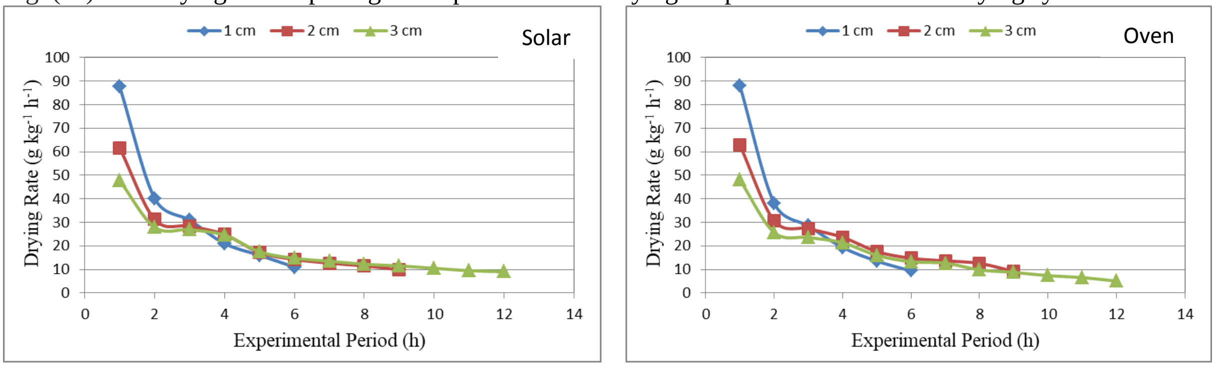

Fig. (6b): The drying rate of pomegranate peels at 60 °C drying temperature for different drying systems.

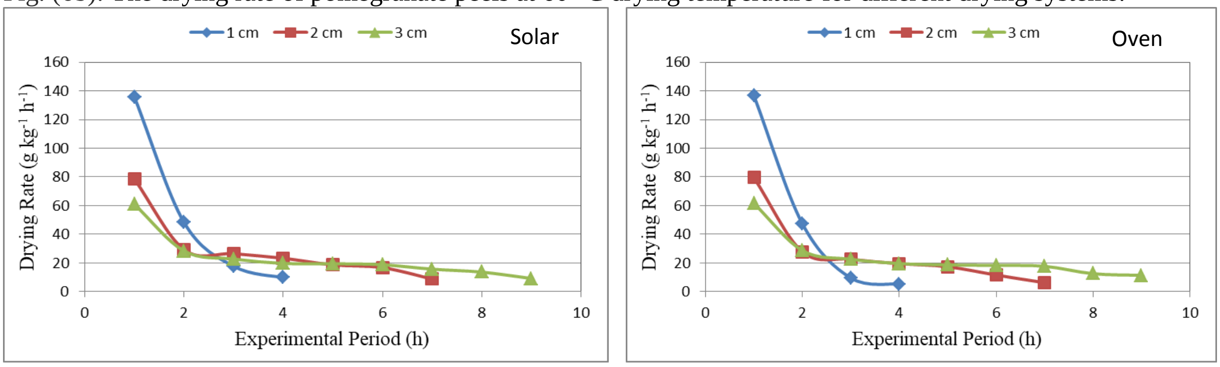

Fig. (6c): The drying rate of pomegranate peels at 70 °C drying temperature for different drying systems.

The results indicate that the drying rate of the pomegranate peels dried under the hybrid solar drying system at 70 ºC recorded an average of 91.74 g $_{water}$ kg^{-1} h $^{-1}$ after hour of drying depending on the layer thicknesses of 1, 2 and 3cm. The drying rate decreased gradually with the drying to reach 9.78 g $_{water}$ kg^{-1} h $^{-1}$ after 4 hours for the 1cm layer thickness, while it reached 8.72 g $_{water}$ kg^{-1} h $^{-1}$ after 7 hours for the 2cm layer thickness, and it reached 9.15 g $_{water}$ kg^{-1} h $^{-1}$ after 9 hours for the 3cm layer thickness. For the oven drying system, the drying rate of the pomegranate peels dried at 70 ºC recorded an average of 99.46 g $_{water}$ kg^{-1} h $^{-1}$ after hour of drying depending on the layer thicknesses of 1, 2 and 3cm. The drying rate decreased gradually with the drying to reach 5.33 g $_{water}$ kg^{-1} h $^{-1}$ after 4 hours for the 1cm layer thickness, while it reached 6.21 g $_{water}$ kg^{-1} h $^{-1}$ after 7 hours for the 2cm layer thickness, and it reached 11.33 g $_{water}$ kg^{-1} h $^{-1}$ after 9 hours for the 3cm layer thickness. These results agreed with those obtained by **[13]**.

Energy consumption

Fig. 7 shows the energy consumption for drying pomegranate peels affected by drying systems, drying temperature and layer thickness of the pomegranate peels. The results showed that the energy consumption for drying pomegranate peels was affected gradually by the drying temperature while, it affected inversely by the layer thickness, where the results indicate that the highest energy consumption was at a temperature of 50 °C and a product thickness of 1 cm was 2116.4 W kg^{-1}, and the lowest energy consumption was at a temperature of 70 °C with a thickness of 3 cm and it was 961.4 W kg^{-1} in the hybrid solar system. As for the oven, the highest energy consumption was at a temperature of 50 °C and a thickness of 1 cm and it was 7769.0 W kg^{-1}, while the lowest energy consumption at 70 °C and 3 cm thick was 3453.7 W kg^{-1}.

The results also show that the energy requirement for drying pomegranate peels under the oven drying system was more than those of the hybrid solar drying system. It could be seen that, the average energy requirement for drying pomegranate peels was 1491.93, 1155.87 and 1103.67 and 5594.17, 4829.10 and 40.16.23 W kg^{-1} at 50, 60 and 70 °C drying temperature, respectively, for hybrid solar and oven drying systems. Also, the average energy requirement for drying pomegranate peels was 1648.80, 1126.67 and 967.00 and 6334.07, 4337.87 and 3767.57 W kg^{-1} at 1, 2 and 3 cm layer thickness, respectively, for the hybrid solar and the oven drying systems. The trend of these results agreed with those obtained by **[29]** and **Seyfi *et al (2021)***.

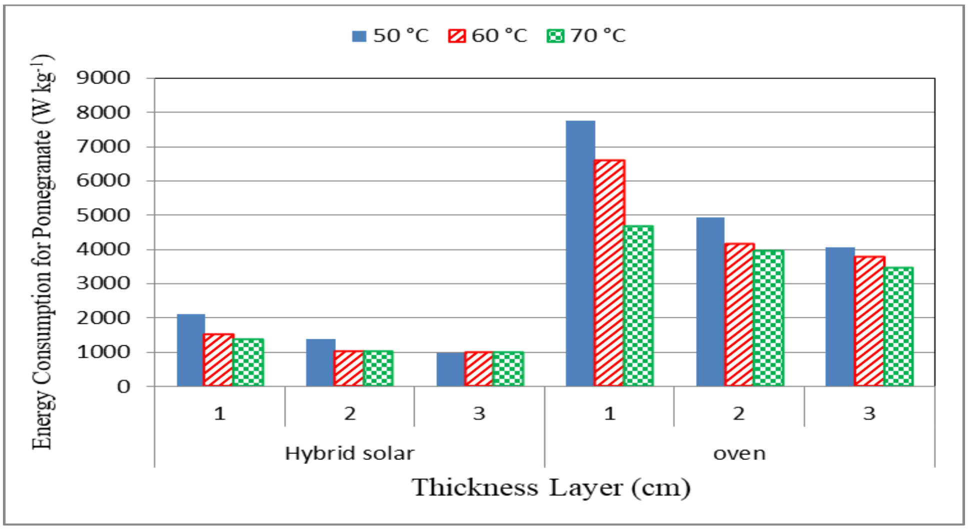

Fig. (7): Energy consumption for drying pomegranate peels under different drying systems and different drying temperatures

Total costs

Fig. 8 shows the total cost for the pomegranate peels affected by drying systems, drying temperature and layer thickness of the pomegranate peels. The results showed that the energy consumption for drying pomegranate peels was affected gradually by the drying temperature while, it affected inversely by the layer thickness, where the results indicate that the total cost of dried pomegranate peels decreases was increasing drying temperature and layer thickness. It could be seen that, the total cost of dried pomegranate peels was decreased from 9.83 to 9.15, 9.47 to 8.91 and 9.07 to 8.75 LE kg^{-1}, when the drying temperature increased from 50 to 70 °C for 1, 2 and 3 cm layer thickness, respectively, for the hybrid solar drying system. Also, the total cost of dried pomegranate peels was decreased from 13.61 to 11.63, 11.69 to 10.99 and 11.08 to 10.71 LE kg^{-1}, when the drying temperature increased from 50 to 70 °C for 1, 2 and 3 cm layer thickness, respectively, for the oven drying system. The trend of these results agreed with those obtained by **[20]**.

The results indicate that, the cost of dried pomegranate peels that dried under the hybrid solar drying system was less than those of oven drying system. The results indicate that the highest cost of drying pomegranate peels was at a temperature of 50 °C and a thickness of the plant layers 1 cm was 9.83 LE kg^{-1}, and the lowest cost consumption was at 70 °C with a thickness of 3 cm, and it was 8.75 LE kg^{-1} in the hybrid solar system. As for the oven, the highest cost was at a temperature of 50 °C and a thickness of 1 cm, and it was 13.62 LE kg^{-1} and the lowest cost consumption was at 70 °C with a thickness of 3 cm, and it was 10.71 LE kg^{-1}. The trend of these results agreed with those obtained by **[30]**.

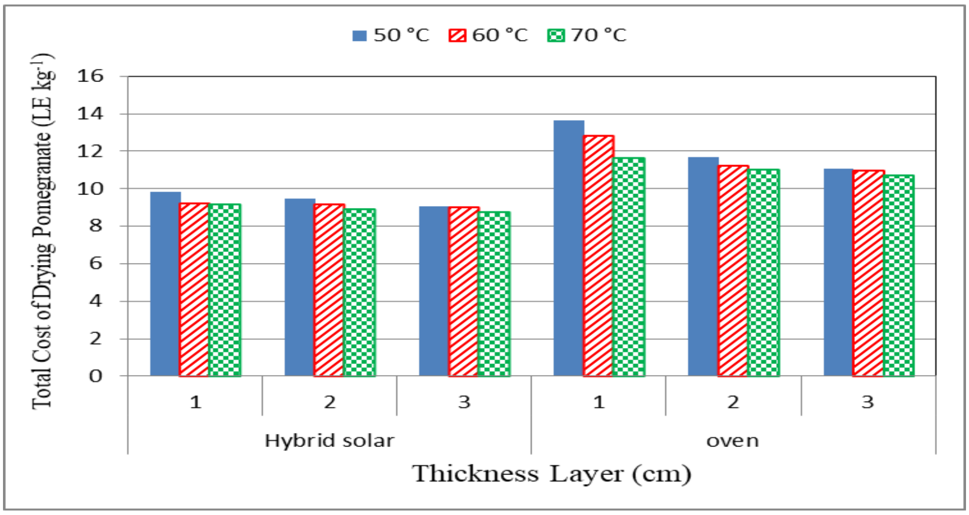

Fig. 8. Total cost for drying pomegranate peels under different drying systems and different drying temperatures.

Conclusion

The experiment was carried out to study the effect of drying systems, drying temperature and different layer thickness on the weight losses, moisture level, rate of drying, energy consumption and cost. The obtained results can be summarized as follows:

The weight loss of pomegranate peels increased from 74.65 to 76.44, 73.30 to 76.02 and 72.94 to 75.11 and 75.68 to 77.72, 74.91 to 76.88 and 74.56 to 76.13 %, for 1, 2 and 3 cm layer thickness, respectively, when the drying temperature increased from 50 to 70 °C, respectively.

The moisture level of pomegranate peels increased from 215.10 to 226.52, 217.68 to 239.94 and 224.25 to 258.68 and 218.88 to 229.32, 221.93 to 243.36 and 226.94 to 263.75% d.b., for 1, 2 and 3 cm layer thickness, respectively, when the drying temperature increased from 50 to 70 °C, respectively.

The drying rate of pomegranate peels ranged from 60.89 to 135.75 and 61.44 to 136.50 g_{water} kg^{-1} h^{-1} for hybrid solar and oven drying systems, respectively.

The energy consumption values were 2017.7 and 7737.7 W kg^{-1} for hybrid solar and oven systems, respectively, for low layer thickness.

The highest cost of drying pomegranate peels was at a temperature of 50 °C and a thickness of the plant layers of 1 cm was 9.83 LE kg^{-1}.

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