Drying of tomato fruits using solar energy

Heba Abdel Mohsen[1], A. A. Abd El-Rahmam[2*], H. E. Hassan[3]

(1. *Researcher, Agric. Eng. Res. Institute, Agric. Res. Center, Egypt*;
2. *Prof. of Agric. Eng. Res. Institute, Agric. Res. Center, Egypt*;
3. *Prof. of National Institute of Laser Enhanced Sciences (NILES), Cairo University, Egypt*)

Abstract: The main aims of this work are fabricating simple solar dryer for tomatoes fruits drying, solar dryer and open solar drying were used to dry tomato slices, and study of drying time influences on moisture content losses and weigh of tomatoes slices. Also, to study various parameters such as relative humidity, temperature and velocity of air on tomatoes drying and compared to solar dryer and open solar dried during tomatoes fruits drying. Tomatoes are sliced to a thickness of about 1, 1.5 and 2.5 cm. The sliced tomatoes are arranged in single, two and three layers on surface of mats and left to dry naturally in the open solar and in solar dryer. Tomatoes dried at a time vary, based on the thickness layers of slices. Obtained results were:

- The weight of all tomato slices was decreased by increasing drying time in opened solar drying and inside fabricated solar dryer. The weight of dried tomato slices was lower under the drying inside fabricated solar dryer than the drying in opened solar drying method.
- The losses of moisture content of all tomato slices were increased by increasing drying time in opened solar drying. But, the losses of moisture content of dried tomato slices were higher under the drying inside fabricated solar dryer than the drying in opened solar drying method. Because of the moisture content of all tomato slices was decreased by increasing drying time in opened solar drying. But, the moisture content of dried tomato slices was lower under the drying inside fabricated solar dryer than the drying in opened solar drying method.
- The solar dryer appears to be the effective and faster method of drying of tomatoes slices, because the drying time is very less compared with open solar drying. This is due to the solar drying effect inside the solar dryer where the temperature inside the dyer keeps on increasing with decrease in relative humidity inside the dryer.

Keywords: Tomato, moisture content, solar dryer, open solar drying, and drying time

Citation: Abdel Mohsen, H., A. A. Abd El-Rahmam, and H. E. Hassan. 2019. Drying of tomato fruits using solar energy. Agricultural Engineering International: CIGR Journal, 21(2): 204–215.

1 Introduction

In the present days, the demand for the tomatoes is increasing steadily with an increase in population and its likeliness towards tomato. The world average yield of tomato is 23tonnes per hectare. At current time, spoilage of fresh tomatoes is significant. Most of the natural food drying methods can hardly provide products with desired specifications because of adequate hygienic conditions. Moreover, drying processes carried with conventional fuel under a closed system have a high cost. Therefore, systems using renewable energy sources like geothermal and solar energy have become more widespread (Bansal, 1999).

Tiris et al. (1994) mentioned that there were two methods to avoid spoilage and wastage of food stuffs especially tomatoes. The first was the cold storage method where the food stuffs will be stored in a highly refrigerated room thereby enhancing the small-scale farmers to meet the sudden and high demands in the market without any significant wastage. This method is an expensive one and small-scale farmers cannot afford it. The second method is the product drying which is the most appropriate solution for reducing spoilage, gaining prolonged shelf-life and enhancing the market value of the products, thereby allowing poor small-scale farmers to achieve profit.

Received date: 2018-09-24 **Accepted date:** 2018-11-01

* **Corresponding author: A. A. Abd El-Rahman,** Ph.D., Professor of Agricultural Engineering, Agricultural Engineering Institute, 256 Dokki, Egypt. Email: abdo_aaaa2000@yahoo.com.

Vazquez et al. (1997) dried grapes using a closed-loop drying mechanism heat pump at different air speed rates and temperatures. Although grapes dried in about 40 days under natural drying conditions, this time reduced to 24 hours with the heat pump assisted system. The authors reported that raisin characteristics like color and quality did not alter with this drying system, suggesting that such a drying system should be used in industrial applications efficiently.

A greenhouse is essentially an enclosed structure which traps the short wavelength solar radiation and stores the long wavelength thermal radiation to create a favorable micro-climate for higher productivity. A greenhouse heating system is used to increase the thermal energy storage inside the greenhouse during the day or to transfer excess heat from inside the greenhouse to the heat storage area. This heat is recovered at night to satisfy the heating needs of the solar tunnel greenhouse dryer. Thus, the temperature inside the dryer will be increasing steadily, thereby ensure quicker drying of the products than the open sun drying method. Various investigators have studied the greenhouse for crop drying (Garg and Kumar, 2000).

Drying process is the most significant form of food preservation and also for its extended shelf-life. It is a simultaneous heat and mass transfer process in which moisture is removed from the food material by the hot air. In this purpose, there have been many studies on the drying behavior of vegetables and fruits such as sweet pepper and garlic (Condori et al., 2001), tomato seed (Sogi et al., 2003).

One of the major problems caused by these energy sources is sustainability. Such a problem that may occur before the drying process may cause foods to decay. Therefore, in practice, systems working with fuel and electricity were incorporated to these systems. Drying systems are used not only for fruits and vegetables, but also for products such as tobacco, tea leaf, hazelnut, corn and in many areas such as textile, leather, rubber and photograph industries. Products dried under natural conditions may be exposed to dust, rain, harmful insects and high temperatures (Madhlopa et al., 2002).

Olajide et al. (2003) estimated food loses due to spoilage and mishandling in the lesser and underdeveloped countries to fall between 25% and 40%. It was noticed that increasing the temperature or velocity of the drying air, the drying time decreased, while the relative humidity decreased (Erenturk et al., 2005). On the other hand, increasing the drying air temperature decreased the equilibrium moisture content and the total drying time (Simal et al., 2005). Chen et al. (2005) said that it was difficult to control the quality specifications of final products. Drying processes carried out in a closed system, where drying parameters were better controlled than natural drying; enable to obtain more hygienic and acceptable products.

Fatouh et al. (2006) reported that product type, loading quantity, drying air temperature and air speed had an effect on drying rates. The authors noted that small volume products had shorter drying time and less energy consumption. Unit water quantity displaced, initial product humidity rate, product geometry and diffusion characteristics of product have an important role in drying performance of a system, and drying cost is influenced by the physical feature of a product, air flow and by-pass evaporate rates 10.

Hawlader and Jahangeer (2006) indicated that there was a high demand for inexpensive dried products with high quality. In order to produce better and cheaper dried products, energy must be used in a most productive way. Using free energy sources like solar energy may reduce the drying costs significantly. Kaya et al. (2007) determined the effects of drying air temperature, air flow rate and air relative humidity on the drying kinetics of quince, apple and pumpkin using convective dryer. Samaila et al. (2008) stated that harvested fruits were of high moisture content which under tropical conditions of high temperature and relative humidity were prone to rapid post-harvest deterioration and losses of up to 30%-69%. Therefore, during the vegetable peak period, there were still a lot of vegetables available at low prices and waste. The scarcity or non-availability of these crops in their off seasons continued to be a common and ugly experience of the poor farmers.

Therefore drying of tomatoes with a suitable technology will enhance its shelf-life, prevent the wastage of tomatoes. Open sun drying is a well-known food preservation technique that is still the most common method used to preserve agricultural product in the tropical and subtropical countries. However, tomatoes dried under natural conditions may be exposed to dust, rain and high temperatures. In these conditions some problems such as crack of the structure, bleaching, hard texture, loss of flavor and nutritional properties, low rehydration capacity, on-enzymatic browning which makes tomatoes to worsen in its quality (Cernisev, 2010).

Rasim and Atalay (2012) showed that the tomatoes were cut into either halves or quarters before drying. Besides heat pump dehumidifier (HP) and solar-assisted systems (SAS) at the drying air speed of 2 $m.s^{-1}$ on average, natural drying (ND) was also used for drying experiments. Drying performance of HP was the best. In general, SMER values of tomato quarters were higher than those of tomato halves dried under same conditions. Heat pump system presents great advantages for tomatoes such as faster drying speed, less influence by environmental factors (rain, dust, insects) and less dependence on environmental conditions.

Arunet et al. (2014) mentioned that a natural convection solar tunnel greenhouse dryer was designed and developed for studying the drying characteristics of tomatoes. Three experimental runs with 30 kg of tomatoes were carried out in the dryer during the month of June 2014. The performance of the dryer was studied drying time and product quality in comparison with open sun drying method. It was found that the solar tunnel greenhouse dryer took only 29 hours for reducing the moisture content of tomatoes from 90% (w.b.) to 9% (w.b.) whereas the open sun drying took 74 hours for the same. Also, the quality of dried tomatoes produced from solar tunnel dryer is much superior compared to that of open sun drying.

The main aims of this work are fabricating simple solar dryer for tomatoes fruits drying, solar dryer and open solar drying were used to dry tomato slices, and study of drying time influences on moisture content losses and weigh of tomatoes slices. Also, to studying various parameters such as relative humidity, temperature and velocity of air on tomatoes drying and compared to solar dryer and open solar dried during tomatoes fruits drying.

2 Materials and methods

Experiments were carried out under meteorological conditions of Dakahliya Governorate. It located between latitudes 30.5°, 31.5°, N, and longitudes 30°, 32° east longitude. In Egypt during the November of 2015. On the basis of measurement, at this location was used about 10 h per day. The experiments started at 10:00 a.m., and measurements were done every two hours.

2.1 Sample preparation

Tomatoes (*Lycopersiconesculentum*) harvested with 90% to 94% moisture content wet basis, would deteriorate after 3 to 5 days. Therefore, they were dried until their moisture contents were reduced to about10%.

Tomatoes (25 kg for each experiment) were cut into different thickness of about 1.0, 1.5 and 2.0 cm. The sliced tomatoes were used in one, two and three layers on surface of shelves and left to dry naturally in the open solar and in solar dryer. Tomatoes dried at a time vary, based on the thickness of slice and layers of slices.

2.2 Solar dryer

The solar dryer sampled from local materials were fabricated and tested at Agricultural Engineering Research Institute, Agricultural Research Institute; Egypt is shown in Figure 1. Tomatoes on glasses shelves were weighed at different time intervals to measure moisture and weight loss.

The solar radiation is transmitted into the solar dryer by the glass film. This glass film allows all the outside solar radiations to pass into the solar dryer and prevents the re-radiation from the solar dryer to the outside and there by helps accumulating the heat the atmosphere inside the solar dryer. Therefore, the temperature inside the solar dryer was more than the ambient temperature. This will help to remove the moisture content of the tomatoes slices placed inside the solar dryer and therefore they get dried.

2.3 Instrumentation

2.3.1 Ambient air and solar dryer air outlet temperature

Ambient air and solar dryer air outlet temperature were measured with a digital type - T- thermocouple of a 24- channel outlet, omega digital thermometer and mercury–in–glass thermometer.

2.3.2 Wind speed

The wind speed outside and inside the dryer was measured using wind vane anemometer.

2.3.3 Air flow rate

Air flow rate was produced by a fan speed. Solar energy system was installed with 45º fixed angle to collect more solar radiation with heat air drying in Dakahlia Governorate where the experiments were carried out.

2.3.4 Determination of Moisture Content

The drying sliced tomatoes in the solar dryer and open solar were sampled out periodically and the moisture content in wet basis was measured by oven drying method. Measurements were done at two hours intervals in the day time for each batch drying.

Samples were cut and kept in electrical oven, maintained at 105±1°C for 5 h. Initial (m_i) and final mass (m_f) at time t. Samples were recorded using electronic balance and repeated every 1 h interval till end of drying. Moisture content on wet basis (M_{wb}) is defined as

$$M_{wb}=(m_i-m_f)/m_i$$

where, m_i and m_f are initial and final weight of samples respectively.

Figure 1 Solar dryer and solar open drying of tomatoes slice

3 Results and discussion

In the present study, the effect of drying method, drying time, weight of tomatoes, thickness of slice and tomato slice layers in the drying system on drying time were studied.

The results indicated in solar dryer, the percentage of drying time was about 56%, 27.5% and 23.1% faster than solar opened drying which was about 35.9%, 21.6% and 18.7% for 1, 2 and 3 layers slices of tomatoes, respectively at drying tomato slices with 1 cm thickness. It was found that lighter tomatoes one layer and dried faster than two and three layers of tomatoes slices.

Percentage of drying time of tomato slices with 1.5 cm thickness in solar dryer were about 24.2, 19.4 and 15.9% faster than solar opened drying which were about 19.5%, 16.2% and 13.7% for 1, 2 and 3 layers slices of tomatoes, respectively.

At drying tomato slices with 2 cm thickness, drying time of tomato slices in solar dryer was about 16.6%, 13.5% and 10.9% faster than solar opened drying which was about 14.3, 11.9 and 9.8% for 1, 2 and 3 layers slices of tomatoes, respectively.

Figure 2 shows values of weather factors during drying of tomatoes including ambient temperature, air speed and relative humidity through days in November in Mansora region at Dakhlya Governorate.

The values of weather factors during drying of tomatoes including ambient temperature, air speed and relative humidity through days of number month. It noticed that the values (Maximum, average and minimum) of high, average and low ambient temperature were (29^{o}C, 25^{o}C and 22^{o}C), (23^{o}C, 20.5^{o}C and 18^{o}C) and (19^{o}C, 16^{o}C and 14^{o}C) respectively, the values (Maximum, average and minimum) of high, average and low ambient relative humidity were (100%, 85.23% and 59%), (81%, 64.1% and 43%) and (62%, 36.27% and 19%), respectively, and the values (Maximum, average and minimum) of high, and average ambient air speed were (37, 19.5 and 11 km h^{-1}) and (14, 7.13 and 2 km h^{-1}), respectively.

During the period of drying, the relative humidity of the dryer varied between 41% and 77% whereas the ambient relative humidity varies between 59% and 85%. Because of the decreased relative humidity inside the dryer (due to the solar dryer effect), the temperature inside the dryer was high , varied between 22^{o}C and 25^{o}C which is sufficient enough to dry the tomatoes. Whereas, the ambient temperature was varied between 29^{o}C and 36^{o}C%.

During the period of drying, the ambient air velocity varied between 19 and 39 m s^{-1} whereas the dryer air velocity varied between 11 and 13 m s^{-1}. It was evident that the dryer air velocity is lesser than the ambient air velocity due to there is no natural convection. This is the reason for the lower air velocity and increased drying rate inside the dryer.

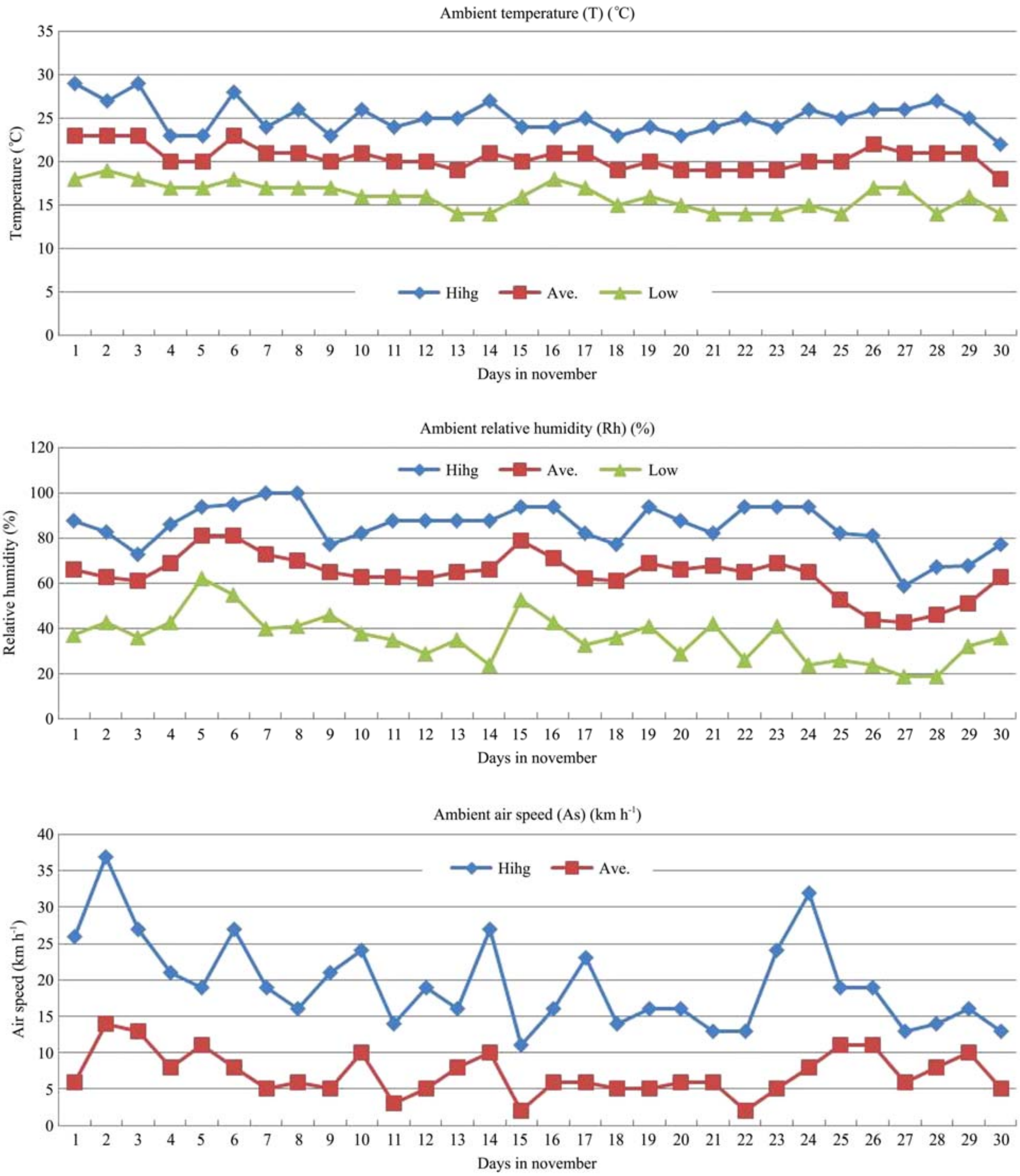

Figure 2 Values of weather factors during drying of tomatoes (Temperature (T), air speed (As) and relative humidity (Rh)

Figures 3, 4 and 5 show that the relation between weight of tomato slices and drying time with different thickness of tomato slices (1, 1.5 and 2 cm) and different layers of slices (1, 2 and 3 layers) during tomato drying inside fabricated solar dryer. It was found that the tomato slices have 3 layers was higher of the weight (60.06 g). While, the tomato slices have 1 layer was lower of weight (17.43 g). But, the weight of sample with two layers slices was intermediate between samples with one and three layers of slices (38.9 g).

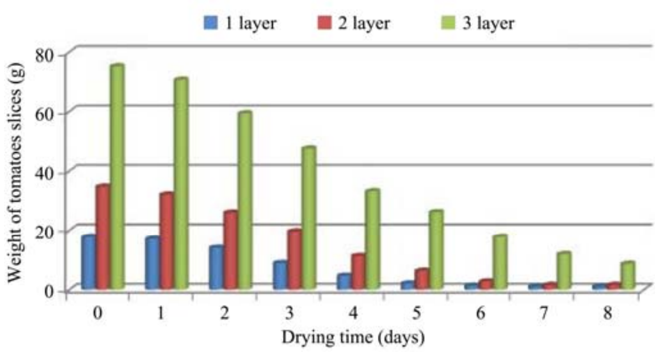

Figure 3 Weight of different tomatoes slices during drying in solar drying inside solar dryer with thickness 1 cm

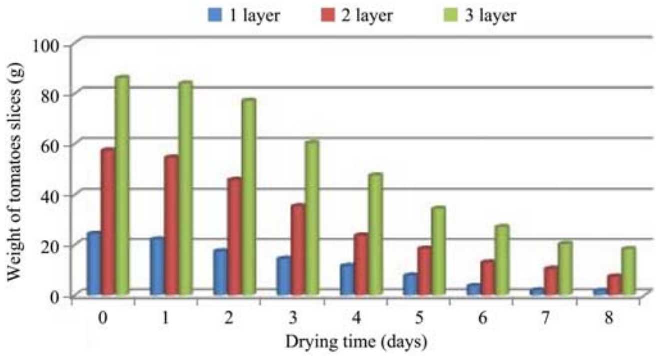

Figure 4 Weight of different tomatoes slices during drying in solar drying inside solar dryer with thickness 1.5 cm

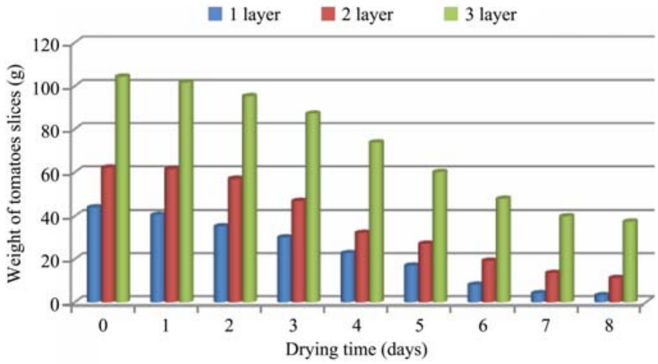

Figure 5 Weight of different tomatoes slices during drying in solar drying inside solar dryer with thickness 2 cm

Also, it was noticed that the weight of all tomato slices was decreased by increasing drying time inside fabricated solar dryer.

The weight of tomatoes slices with thickness 1 cm was decreased (from 17.43 to 1.0 g), (from 38.9 to 1.97 g), and (from 60.06 to 6.33 g) for layers one, two, and three of tomatoes slices, respectively. Also, slices with thickness 1.5 cm was decreased (from 27.23 to 1.7 g), (from 68.36 to 8.50 g), and (from 109.46 to 19.66 g) for layers one, two, and three of tomatoes slices, respectively. As well as, slices with thickness 2 cm was decreased (from 40.63 to 3.30 g), (from 61.57 to 11.33 g), and (from 101.70 to 37.53 g) for layers one, two, and three of tomatoes slices, respectively.

Figures 6, 7 and 8 indicate that the relation between weight of tomato slices and drying time with different thickness of tomato slices (1, 1.5 and 2 cm) and different layers of slices (1, 2 and 3 layers) during tomato drying in opened solar drying. It was found that the tomato slices have 3 layers was higher of the weight (70.83 g). While, the tomato slices has 1 layer was lower of weight (17.23 g). But, the weight of sample with two layers slices was intermediate between samples with one and three layers of slices (23.10 g).

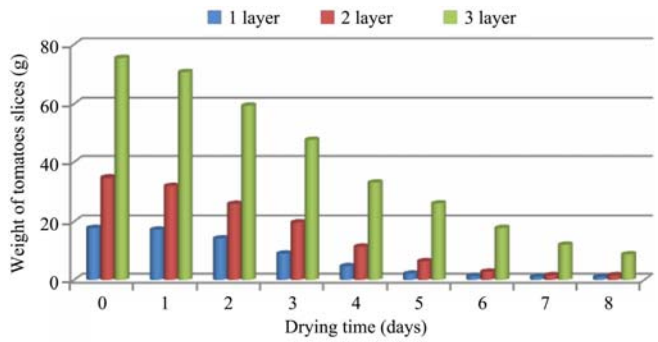

Figure 6 Weight of different tomatoes slices during drying in opened solar drying with thickness 1 cm

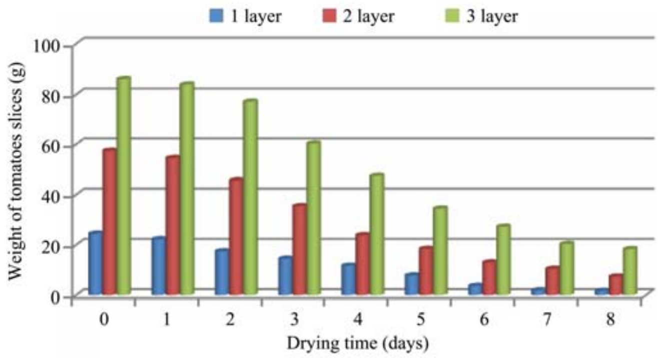

Figure 7 Weight of different tomatoes slices during drying in opened solar drying with thickness 1.5 cm

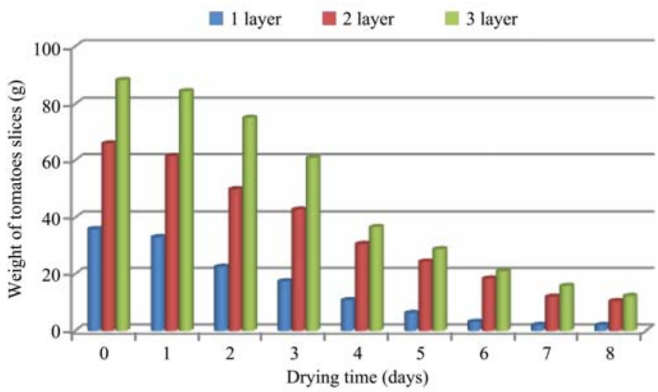

Figure 8 Weight of different tomatoes slices during drying in opened solar drying with thickness 2 cm

The weight of tomatoes slices with thickness 1 cm was decreased (from 17.23 to 1.0 g), (from 32.1 to 1.6 g), and (from 70.83 to 8.73 g) for layers one, two, and three of tomatoes slices, respectively. Also, slices with thickness 1.5 cm was decreased (from 22.23 to 1.7 g), (from 45.35 to 7.43 g), and (from 84.06 to 18.33 g) for layers one, two, and three of tomatoes slices, respectively. As well as, slices with thickness 2 cm was decreased (from 33.07 to 1.90 g), (from 61.40 to 10.37 g), and (from 84.47 to 12.17 g) for layers one, two, and three of tomatoes slices, respectively.

Also, it was noticed that the weight of all tomato slices was decreased by increasing drying time in opened solar drying. But, the weight of dried tomato slices was lower under the drying inside fabricated solar dryer than the drying in opened solar drying method.

Figures 9, 10 and 11 illustrate that the relation between losses weight of tomato slices and drying time with different thickness of tomato slices (1, 1.5 and 2 cm) and different layers of slices (1, 2 and 3 layers) during tomato drying inside fabricated solar dryer. It was found that the tomato slices have 1 layer were lower of the losses weight (0.73 g). While, the tomato slices have 3 layers were higher of losses weight (1.87 g). But, the weight of sample with two layers slices was intermediate between samples with one and three layers of slices (0.90 g).

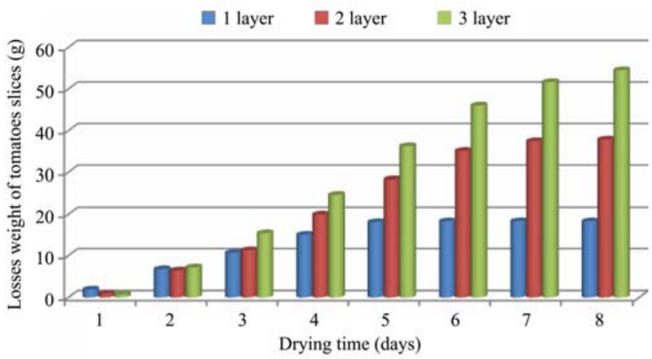

Figure 9 Losses weight of different tomatoes slices during drying in solar drying inside solar dryer with thickness 1 cm

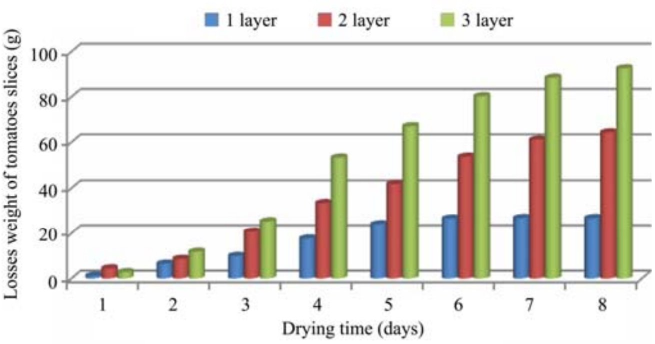

Figure 10 Losses weight of different tomatoes slices during drying in solar drying inside solar dryer with thickness 1.5 cm

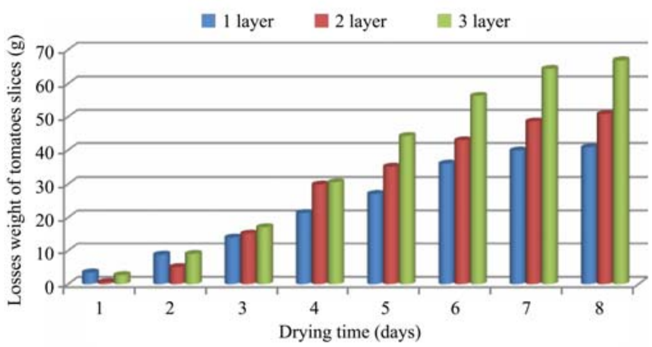

Figure 11 Losses weight of different tomatoes slices during drying in solar drying inside solar dryer with thickness 2 cm

The losses weight of tomatoes slices with thickness 1 cm was increased (from 0.73 to 18.3 g), (from 0.90 to 37.83 g), and (from 1.87 to 45.47 g) for layers one, two, and three of tomatoes slices, respectively. Also, slices with thickness 1.5 cm was increased (from 1.16 to 26.70 g), (from 2.7 to 64.30 g), and (from 4.43 to 92.53 g) for layers one, two, and three of tomatoes slices, respectively. As well as, slices with thickness 2 cm was increased (from 0.63 to 40.80 g), (from 2.70 to 50.87 g), and (from 3.47 to 66.87 g) for layers one, two, and three of tomatoes slices, respectively.

Also, it was noticed that the losses weight of all tomato slices was increased by increasing drying time inside fabricated solar dryer.

Figures 12, 13 and 14 show that the relation between losses weight of tomato slices and drying time with different thickness of tomato slices (1, 1.5 and 2 cm) and different layers of slices (1, 2 and 3 layers) during tomato drying in opened solar drying. It was found that the tomato slices have one layer were lower of the losses weight (0.57 g). While, the tomato slices have three layers were higher of losses weight (4.57 g). But, the weight of sample with two layers slices was intermediate between samples with one and three layers of slices (2.70 g).

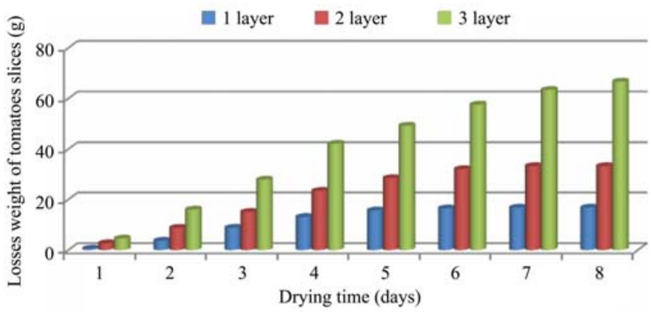

Figure 12 Losses weight of different tomatoes slices during drying in opened solar drying with thickness 1 cm

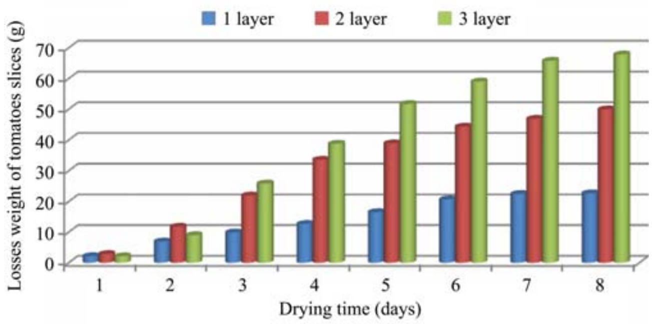

Figure 13 Losses weight of different tomatoes slices during drying in opened solar drying with thickness 1.5 cm

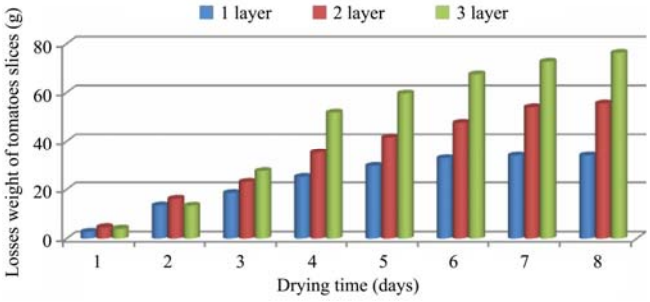

Figure 14 Losses weight of different tomatoes slices during drying in solar drying inside solar dryer with thickness 2 cm

The losses weight of tomatoes slices with thickness 1 cm was increased (from 0.57 to 16.80 g), (from 2.70 to 33.20 g), and (from 4.57 to 66.67g) for layers one, two, and three of tomatoes slices, respectively. Also, slices with thickness 1.5 cm was increased (from 2.13 to 22.70 g), (from 2.16 to 49.97 g), and (from 2.86 to 67.87 g) for layers one, two, and three of tomatoes slices, respectively. As well as, slices with thickness 2 cm was increased (from 2.83 to 34.00 g), (from 3.93 to 55.53 g), and (from 4.50 to 76.23 g) for layers one, two, and three of tomatoes slices, respectively.

Also, it was noticed that the losses weight of all tomato slices was increased by increasing drying time in opened solar drying. But, the losses weight of dried tomato slices was higher under the drying inside fabricated solar dryer than the drying in opened solar drying method.

Figures 15, 16 and 17 show that the relation between losses of moisture content of tomato slices and drying time with different thickness of tomato slices (1, 1.5 and 2 cm) and different layers of slices (1, 2 and 3 layers) during tomato drying inside fabricated solar dryer. It was found that the tomato slices have one layer were higher of the losses of moisture content (9.67%). While, the tomato slices have three layers were lower of losses moisture content (1.20%). But, the weight of sample with two layers slices was intermediate between samples with one and three layers of slices (2.26%).

The Losses of moisture content of tomatoes slices with thickness 1 cm was increased (from 9.67 to 94.81%), (from 2.26 to 95.05%) and (from 1.20 to 89.58%) for layers one, two, and three of tomatoes slices, respectively. Also, slices with thickness 1.5 cm was increased (from 4.10 to 94.01%), (from 6.09 to 88.32%) and (from 2.43 to 82.47%) for layers one, two, and three of tomatoes slices, respectively. As well as, slices with thickness 2 cm was increased (from 7.86 to 92.51%), (from 1.01 to 81.77%), and (from 2.58 to 64.04%) for layers one, two, and three of tomatoes slices, respectively.

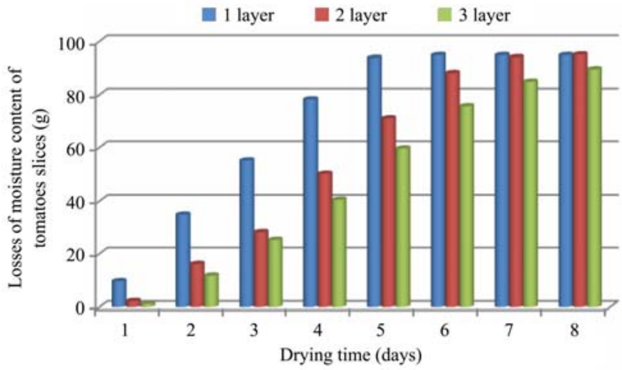

Figure 15 Losses of moisture content of different tomatoes slices during drying in solar drying inside solar dryer with thickness 1 cm

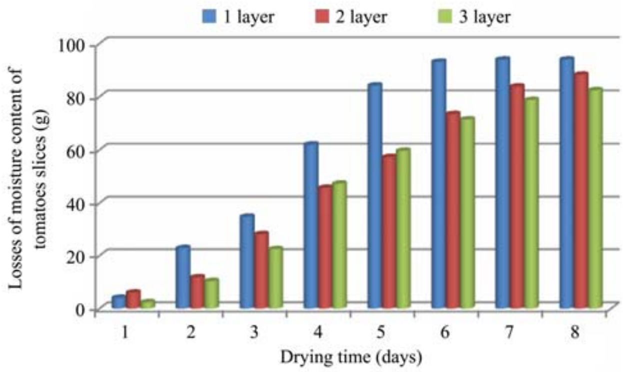

Figure 16 Losses of moisture content of different tomatoes slices during drying in solar drying inside solar dryer with thickness 1.5cm

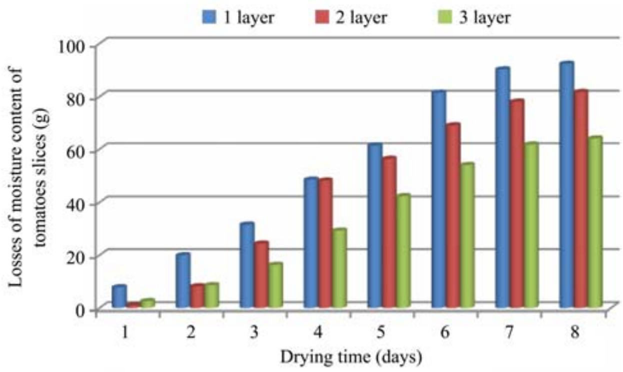

Figure 17 Losses of moisture content of different tomatoes slices during period of solar drying inside solar dryer with thickness 2 cm

Also, it was noticed that the losses of moisture content of all tomato slices were increased by increasing drying time inside fabricated solar dryer.

Figures 18, 19 and 20 show that the relation between losses of moisture content of tomato slices and drying time with different thickness of tomato slices (1, 1.5 and 2 cm) and different layers of slices (1, 2 and 3 layers) during tomato drying in opened solar drying. It was found that the tomato slices have one layer were lower losses of moisture content (3.18%). While, the tomato slices have three layers were higher losses of moisture content (7.75%). But, the weight of sample with two layers slices was intermediate between samples with one and three layers of slices (6.05%).

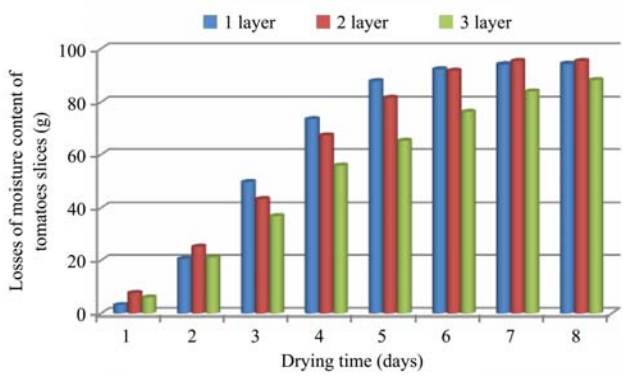

Figure 18 Losses of moisture content of different tomatoes slices during period of opened solar drying with thickness 1 cm

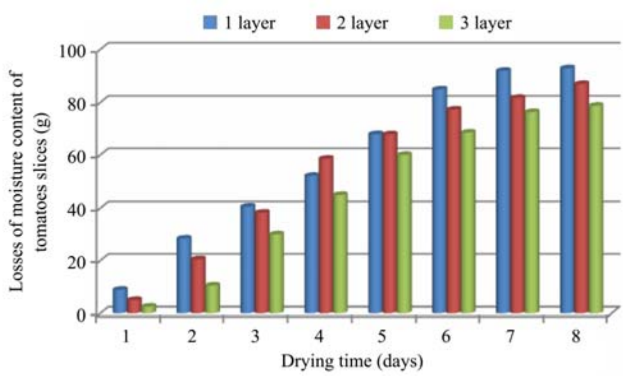

Figure 19 Losses of moisture content of different tomatoes slices during drying by opened solar drying with thickness 1.5 cm

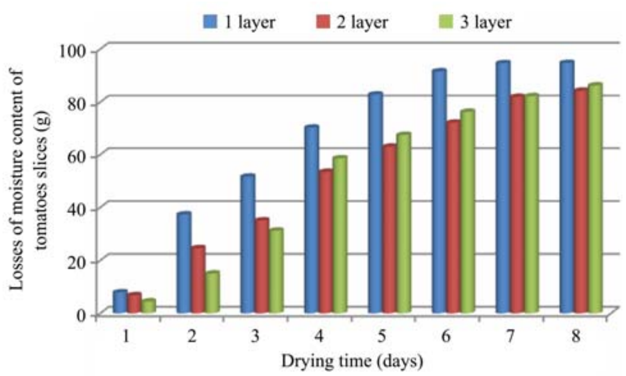

Figure 20 Losses of moisture content of different tomatoes slices during drying by opened solar drying with thickness 2 cm

The Moisture content losses of tomatoes slices with thickness 1 cm was increased (from 3.18 to 94.83%), (from 6.02 to 94.38%) and (from 7.75 to 88.41%) for layers one, two, and three of tomatoes slices, respectively. Also, slices with thickness 1.5 cm was increased (from 8.88 to 93.03%), (from 4.99 to 87.05%) and (from 2.47 to 78.73%) for layers one, two, and three of tomatoes slices, respectively. As well as, slices with thickness 2 cm was increased (from 7.89 to 94.70%), (from 6.82 to 48.26%), and (from 4.44 to 86.23%) for layers one, two, and three of tomatoes slices, respectively.

Also, it was noticed that the losses of moisture content of all tomato slices were increased by increasing drying time in opened solar drying. But, the losses of moisture content of dried tomato slices were higher under the drying inside fabricated solar dryer than the drying in opened solar drying method.

Figures 21, 22 and 23 show that the relation between moisture content of tomato slices and drying time with different thickness of tomato slices (1, 1.5 and 2 cm) and different layers of slices (1, 2 and 3 layers) during tomato drying inside fabricated solar dryer. It was found that the tomato slices have three layers were higher of the moisture content (90.32%). While, the tomato slices have one layer were lower of moisture content (98.74%). But, the weight of sample with two layers slices was intermediate between samples with one and three layers of slices (97.73%).

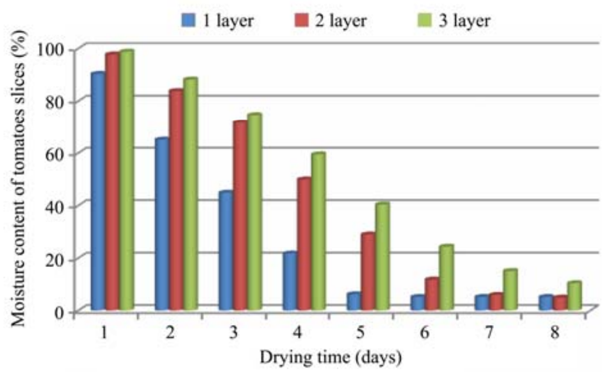

Figure 21 Moisture content of different tomatoes slices during period of solar drying inside solar dryer with thickness 1 cm

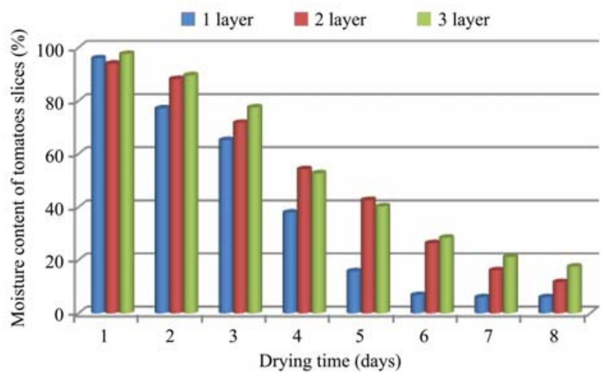

Figure 22 Moisture content of different tomatoes slices during period of solar drying inside solar dryer with thickness 1.5 cm

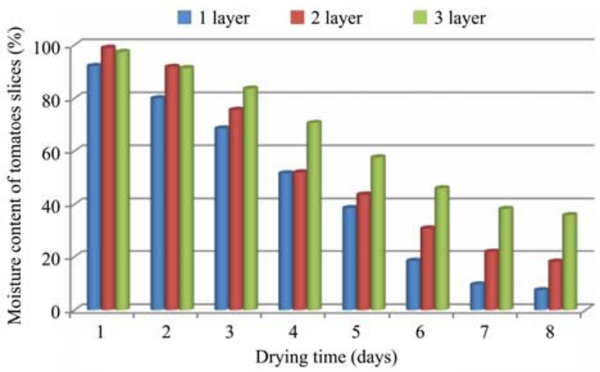

Figure 23 Moisture content of different tomatoes slices during period of solar drying inside solar dryer with thickness 2 cm

The moisture content of tomatoes slices with thickness 1 cm was decreased (from 90.32 to 4.94%), (from 97.73 to 5.18%) and (from 98.74 to 10.41%) for layers one, two, and three of tomatoes slices, respectively. Also, slices with thickness 1.5 cm was decreased (from 93.91 to 5.98%), (from 95.89 to 11.67%) and (from 97.56 to 17.52%) for layers one, two, and three of tomatoes slices, respectively. As well as, slices with thickness 2 cm was decreased (from 92.13 to7. 84%), (from 97.41 to 18.22%), and (from 98.98 to 35.95%) for layers one, two, and three of tomatoes slices, respectively.

Also, it was noticed that the moisture content of all tomato slices was decreased by increasing drying time inside fabricated solar dryer.

Figures 24, 25 and 26 show that the relation between moisture content of tomato slices and drying time with different thickness of tomato slices (1, 1.5 and 2 cm) and different layers of slices (1, 2 and 3 layers) during tomato drying in opened solar drying. It was found that the tomato slices have three layers were higher of the moisture content (90.32%). While, the tomato slices have one layer were lower of moisture content (98.74%). But, the weight of sample with two layers slices was intermediate between samples with one and three layers of slices (97.73%).

The moisture content of tomatoes slices with thickness 1 cm was decreased (from 2.24 to 4.59%), (from 93.94 to 5.61%) and (from 96.81 to 11.58%) for layers one, two, and three of tomatoes slices, respectively. Also, slices with thickness 1.5 cm was decreased (from 91.12 to 6.96%), (from 95.00 to 12.95%) and (from 97.52 to 21.26%) for layers one, two, and three of tomatoes slices, respectively. As well as, slices with thickness 2 cm was decreased (from 92.10 to 5.29 %), (from 93.17 to 13.67%), and (from 95.55 to 15.73%) for layers one, two, and three of tomatoes slices, respectively.

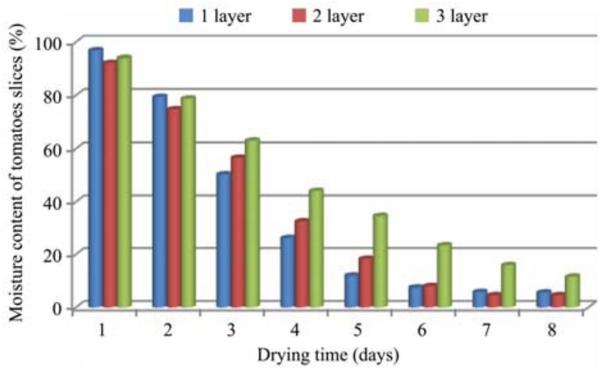

Figure 24 Moisture content of different tomatoes slices during period of opened solar drying with thickness 1 cm

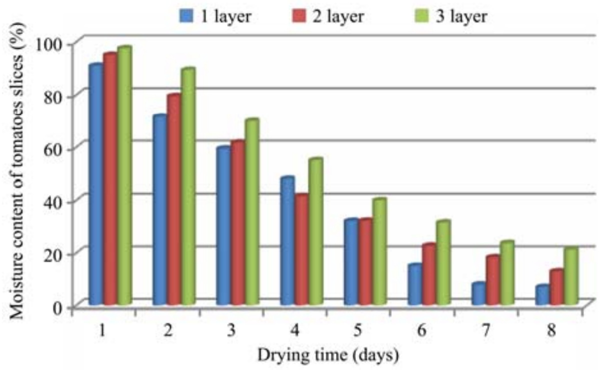

Figure. 25 Moisture content of different tomatoes slices during period of opened solar drying with thickness 1.5 cm

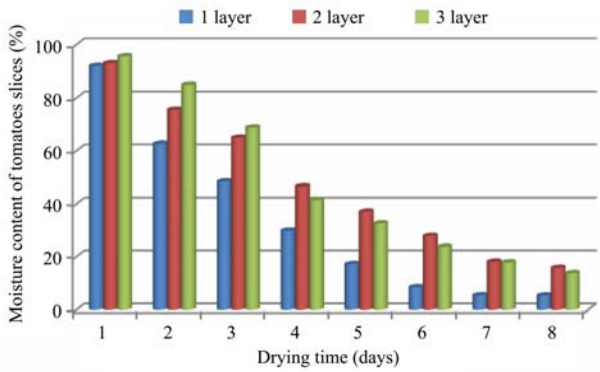

Figure 26 Moisture content of different tomatoes slices during period of opened solar drying with thickness 2 cm

Also, it was noticed that the moisture content of all tomato slices was decreased by increasing drying time in opened solar drying. But, the moisture content of dried tomato slices was lower under the drying inside fabricated solar dryer than the drying in opened solar drying method.

3.1 Variation of drying time in the open solar and inside the solar dryer

3.1.1 For drying of tomatoes slice with 1 cm thickness

Variation of drying time during drying of tomatoes slices in the open solar and inside the solar dryer (Table 1). It was noticed that the differences time were 28, 33, 45 hours lead to increase in drying time percentage 35.89%, 21.56%, 18.78% at drying in the open solar while lead to decrease in drying time percentage 56.0% , 27.5%, and 23.1% at drying inside the dryer for drying tomatoes slices 1 , 2 , and 3 layers, respectively.

Table 1 Variation of drying time during drying of tomatoes slices in the open solar and inside the solar dryer

Thickness (cm)	Layers	Drying time, hr.		Difference hours	Out	Inside
		out	in		Increases (%)	Decreases (%)
1 cm	1	78	50	28	35.89	56.0
	2	153	120	33	21.56	27.5
	3	240	195	45	18.78	23.01
1.5 cm	1	123	99	24	19.5	24.2
	2	185	155	30	16.2	19.34
	3	255	220	35	13.7	15.9
2 cm	1	140	120	20	14.23	16.67
	2	210	185	25	11.9	13.5
	3	295	266	29	9.8	10.9

3.1.2 For drying of tomatoes slice with 1.5 cm thickness

Variation of drying time during drying of tomatoes slices in the open solar and inside the solar dryer (Table 1). It was noticed that the differences time were 24, 30, 35 hours lead to increase in drying time percentage 19.5%, 16.2%, 13.7% at drying in the open solar while lead to decrease in drying time percentage 24.2% , 19.54%, and 15.9% at drying inside the dryer for drying tomatoes slices 1, 2 , and 3 layers, respectively.

3.1.3 For drying of tomatoes slice with 2 cm thickness

Variation of drying time during drying of tomatoes slices in the open solar and inside the solar dryer (Table 1). It was noticed that the differences time were 20, 25, 29 hours lead to increase in drying time percentage 14.23%, 11.9%, 9.8% at drying in the open solar while lead to decrease in drying time percentage 16.67%, 13.5%, and 10.9% at drying inside the dryer for drying tomatoes slices 1 , 2 , and 3 layers, respectively.

The sliced samples of tomato dried with solar dryer and the open solar drying methods. To analyze the system drying efficiencies and this revealed that tomatoes slice. This showed that drying of tomatoes slices can best be achieved by solar dryer than open solar drying. The solar dryer appears to be the effective and faster method of drying of tomatoes slices, because the drying time is very less compared with open solar drying. This is due to the solar drying effect inside the solar dryer where the temperature inside the dyer keeps on increasing with decrease in relative humidity inside the dryer.

4 Conclusion

The main aims of this work are fabricating simple solar dryer for tomatoes fruits drying, and then the solar dryer and open solar drying methods were used to dry tomato slices, the concluded results were as following:

- The overall average solar dryer temperature was higher than solar open drying.
- The results indicated that drying performance is influenced by the product shape (1, 2 and 3 layers of tomatoes slices) in solar dryer and the open solar drying systems.
- The weight of all tomato slices was decreased by increasing drying time in opened solar drying and inside fabricated solar dryer. The weight of dried tomato slices was lower under the drying inside fabricated solar dryer than the drying in opened solar drying method.
- The losses of moisture content of all tomato slices were increased by increasing drying time in opened solar drying. But, the losses of moisture content of dried tomato slices were higher under the drying inside fabricated solar dryer than the drying in opened solar drying method. Because of the moisture content of all tomato slices was decreased by increasing drying time in opened solar drying. But, the moisture content of dried tomato slices was lower under the drying inside fabricated solar dryer than the drying in opened solar drying method.
- The solar dryer appears to be the effective and faster method of drying of tomatoes slices, because the drying time is very less compared with open solar drying. This is due to the solar drying effect inside the solar dryer where the temperature inside the dyer keeps on increasing with decrease in relative humidity inside the dryer.
- The solar dryer appears to be the effective and faster method of drying of tomatoes slices, because the drying time is very less compared with open solar drying. This is due to the solar drying effect inside the solar dryer where the temperature inside the dyer keeps on increasing with decrease in relative humidity inside the dryer.

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