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# Determination of tomato drying conditions with solar energy family type shelf dryer

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**In this study, working parameters of the system consisting of air heaters and dryer with solar energy of 0.20 m$^2$ with a space of 0.72 m$^2$ and 10 pieces in the cabin were investigated experimentally. Average atmospheric air temperature and relative humidity values during the dry daylight hours were measured at 49°C and 35%, respectively. As a result of the examination of the test results, the atmospheric air temperature of 56°C was reached in the dryer depending on the solar radiation and environmental conditions. In addition, the accuracy of solar radiation data in the design of solar energy systems was extremely important. Six different models and MBE, RMSE and t-stat comparison methods were used to calculate the amount of global solar radiation on the horizontal surface. The best results were given by Model-3 with values of MBE=0.130 and RMSE=1.401, while the best result from t-statistics was with t-ist=0.282 with Model-5. When the equations are evaluated statistically, it has been shown that the solar-powered family type shelf dryer and tomato drying conditions can be used for Aksaray province.**

**Key words:** Solar energy, shelf dryer, tomato, solar radiation, relative humidity.

## INTRODUCTION

Drying, which is one of the methods applied for long-term storage of agricultural products, is the oldest method and the largest application area (Yagcioglu, 1996). Drying can be defined as the removal of water or liquid in a substance. The purpose of the drying process is to stop the development of biochemical reactions and microorganisms that may occur in the products by removing free water in wet products and thus reducing the amount of food that can not be bred so that the foodstuffs can last for a long time without deterioration. In a world where conventional energy sources are limited, intensive work is being done to introduce new and renewable energy sources. Among them, solar energy is more preferred than other energy sources because solar drying is a cheap method that does not require any energy and maintenance costs. Approximately 12.6 million tons of tomatoes are produced in Turkey (FAO, 2018). Dried tomato production in Turkey began in small areas in the early 1980s. However, in recent years, it has rapidly increased the production of dried tomatoes (Aksoy and Kaymak, 2016). Nearly all of the tomatoes are dried by spreading on the ground in Turkey (Condori et al., 2001). Drying companies usually process red, spotless, and medium sized tomatoes, which they have collected, through washing, sorting, boiling, cutting, sulphurizing and salting. They are then dried in the sun for drying

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purposes. Areas used as tomato spreading are covered with cover materials and the products that are laid are surrounded by curtains in order to prevent dust, garbage, etc. (Vural and Duman, 2000). These curtains do not prevent the product from being contaminated with various materials even if they hold some of the foreign materials. Companies that trade dried tomatoes are doing different applications (Madhlopa et al., 2002). Some companies dry tomatoes after they have finished all the process. In addition, because of the drying process carried out by the outside, it is not always possible to obtain high quality products due to the weather conditions and direct effects on the product quality (Fuller and Charters, 1997). Since the process of drying the tomatoes on the sun takes a long time, the dried product is affected by the pollutant factors in the environment and also has considerable loss of nutritional properties. Therefore, solar energy dryers have a big precaution in order to shorten the drying time of the product, to obtain the product with the desired moisture content, to make the products cleaner and better quality and not to lose its nutritive properties.

The use of traditional energy sources in the drying process, which is an energy intensive process, causes significant increases in product cost (Ivanova et al., 2003). The use of renewable energy sources such as solar energy is necessary to reduce product costs (Sopian et al., 2000).

The aim of this study was to investigate the drying conditions of tomatoes, which are produced intensively in the province of Aksaray, determine its performance in drying with a shelf type solar dryer that is manufactured for the drying of agricultural products by utilizing solar energy. At the same time, this research aims to expand the use of different types of sun-dried dryers with a simple structure and low cost, which can be manufactured with local facilities, and the drying of tomatoes, other vegetables, and fruits (Ozdemir, 2003). Therefore, a family type dryer is designed, and the results of preliminary experimental studies are given.

## MATERIALS AND METHODS

Herkul F1 (SF / 03), one of the tomato varieties produced in Turkey, was used in this study as drying material. All the samples used in the drying experiments were obtained from the same production site. Drying experiments were carried out in a sun-dried shelf dryer under the conditions of the province of Aksaray. In addition, simultaneous drying in the open-air footed and wire-braided trays under the same irradiation conditions was also taken as a control.

The shelf type dryer in which the drying experiments were made consisted of the air flow solar collector, solar chimney and drying chamber sections (Figure 1). The task of the air solar collector is to convert the incoming solar radiation into heat energy and transfer it to the drying air. The heated air enters the drying chamber under the effect of thermal force and is placed in shelves and passes through drying trays with tomatoes. In the meantime, the product takes moisture and goes out from the chimney.

The air solar collector is 60×120 cm in size, and the wooden case is made of black painted and metal holding element and a transparent cover which keeps the sunlight. The retaining element is composed of 3 pieces of perforated sheet with 1 cm intervals, and the transparent cover consists of two pieces of glass material. The task of the air solar collector is also to send the heated air to the drying chamber by the action of the thermal force and move out of the dryer through the perforated rails, which the products are placed and dampened from the adjustable air outlet openings located on both surfaces.

**Figure 1.** Side view of the shelf type dryer.

There are 10 pieces shelves with the dimension of 34×60 cm in the dryer room. Shelf casings are made of wood material, and steel mesh is used to facilitate air passage. A hinged lid is placed on the rear wall so that the shelves can be placed in the dryer. Schematic view of a solar powered shelf dryer used in the experiment is shown in Figure 2 (Scanlin et al. 1999).

In order to determine the effect of the drying process on the drying characteristics of the tomatoes under different drying periods and environments, solar energy shelf dryers were used in the conditions of Aksaray. The experiments of tomato drying were carried out between 24th July, 2017 and 25th August, 2017. At the beginning of the first experiment, the test materials were weighed and placed on the shelves after the pre-treatments were made by cutting the halves and salting the cut top. The temperature of the air passing through the dryer and the humidity varied depending on the weather conditions at different times during the day and on different days. Tomatoes were simultaneously placed on shelves in three stages in order to properly utilize the air distribution between the shelves. The air collector had an area of 7200 $cm^2$ and there were 10 pieces 0.20 $m^2$ shelves in the cabin. The aim of this study was to shorten the drying period in tomato drying systems and to improve the quality and hygienic conditions. Experimental data were obtained by selecting samples from the total. The sample was placed in a specially prepared mesh so that it would not mix with other products. Climatic changes were taken into consideration during the drying experiment. Properties of dried products such as drying time, color, quality, taste and relative humidity were

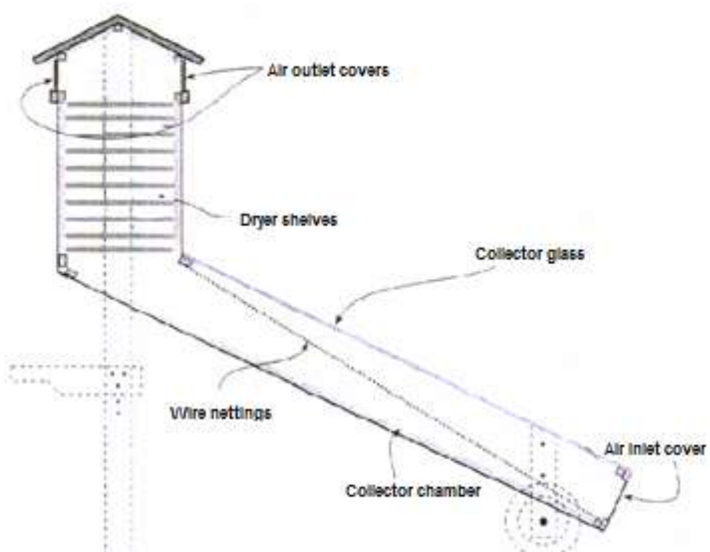


**Figure 2.** Schematic view of a solar powered shelf type dryer.

examined. During the tests, inlet temperature and relative humidity distributions in the dryer, outlet temperature and relative humidity, and total solar radiation from the horizontal surface were continuously measured. Mass losses of dried tomatoes were monitored regularly. Prior to experimental work, the vegetables were immersed in a citric acid solution (2.5 to 5 min). The tomato/solution ratio was taken as 1/3 (Anonymous, 2016). Moreover, average daily and monthly total solar radiation values from the horizontal surface given in the literature for the province of Aksaray (latitude: N 38° 22' 7.054" longitude: E 34° 1' 46.92" and altitude: 980 m) is calculated using a variety of linear, the second and third order equations. In addition, a third-order equation is developed for the daily average solar radiation account in the province of Aksaray. These equations were derived from the average daily and monthly solar irradiance and sunshine values obtained from the measurements taken by the General Directorate of State Meteorology Affairs between 1997 to 2017 and on the horizontal surface and for the province of Aksaray (GDSM, 2017). In the literature, there are various test methods used to evaluate solar radiation prediction models statistically. In this study, the results obtained from different models were compared using Mean Bias Error (MBE), Root Mean Square Error (RMSE) and t-stat (t-ist) methods. The MBE and RMSE values were calculated using the following equations (Machler and Iqbal, 1984).

$$\mathrm{MBE}=\frac{1}{n}\sum_{i=1}^{n}(y_i-x_i) \quad (1)$$

$$\mathrm{RMSE}=\sqrt{\frac{\sum_{i=1}^{n}(y_i-x_i)^2}{n}} \quad (2)$$

In these equations, $x_i$, *i is* measured value, $y_i$, *i is* calculated value, and *n* is the total number of observations. MBE is a measure of the performance of a model over the long term and it is desirable that the value is low. Positive values indicate that the model has a higher value than the real value, while negative values indicate that it gives lower values. The RMSE values give information about the short-term performance of the correlations by showing the deviation between the calculated and measured values. The smaller the RMSE value, the higher the performance of the model. As can be seen from the above explanations, it is clear that each test (RMSE and MBE) alone is not sufficient to show the model performance. It is possible for a model to have a small MBE value versus a large RMSE value. On the other hand, it is also possible that a model has a very small RMSE value but a very small MBE value (Stone, 1993). Therefore, t-statistics were used in addition to the study. A statistical indicator, t-statistics, is used to compare models, as well as whether the values calculated from the models have statistical significance at a certain level of confidence. The t-statistic is calculated according to the values of MBE and RMSE as follows:

$$\text{t - statistic}=\left(\frac{(n-1)MBE^2}{RMSE^2-MBE^2}\right)^{1/2} \quad (3)$$

In this method, the smaller the t-ist value, the better the performance of the model. The t-critical value must first be determined from the statistical tables in order to determine whether the modeled values are statistically significant. Thereafter, the value of tα/2 is found at n-1 degrees of freedom and at α importance level. The t-ist value calculated should be smaller than the t-critical value so that the statistical significance of the calculated values in the 1-α confidence level can be determined. For Aksaray province, the daily total solar radiation from the horizontal surface is calculated from some models available in the literature, and from an equation developed in this study, the results are compared with various comparative methods. Modal-1: Page (Angstrom, 1924), Modal-2: Rietveld (Rietveld et al., 1978), Modal-3: Kilic and Ozturk (Kılıç and Ozturk, 1983), Modal-4: Akinoglu and Ecevit (Akinoglu and Ecevit, 1990), Modal-5: Bahel (Bahel and Bakhsh, 1987), and Modal-6: Louche (Louche et al., 1999). For Aksaray province, the monthly average daily global solar irradiance values and the MBE, RMSE and t-statistic values from the horizontal surface calculated with different models are given in Table 1. According to the models, the comparison of the measured and estimated values of the

**Table 1.** MBE, RMSE and t-Statistic Values ( α=0.01 for n=12 and t-Critical=3,106 for n=12 ) of the models with monthly average global solar radiation ($MJ/m^2$-day) coming to the horizontal surface for Aksaray province.

| Z = 980 m | Aksaray province | $H_{Estimated}$ ( $MJ/m^2$-day) | | | | | |
|---|---|---|---|---|---|---|---|
| Months | $H_ö$($MJ/m^2$-day) | Model 1 (Page) | Model 2 (SolerRietveld) | Model 3 (Kılıç and Öztürk) | Model 4 (Akınoğlu and Ecevit) | Model 5 (Bahel) | Model 6 (Louche) |
| January | 7.86 | 8.17 | 9.06 | 7.72 | 8.70 | 7.06 | 8.40 |
| February | 11.17 | 9.02 | 9.41 | 8.87 | 9.38 | 8.46 | 9.07 |
| March | 14.85 | 13.09 | 14.20 | 13.19 | 13.85 | 12.54 | 13.33 |
| April | 17.51 | 16.87 | 18.41 | 17.37 | 17.01 | 16.27 | 17.25 |
| May | 21.013 | 21.43 | 22.86 | 21.81 | 22.78 | 21.09 | 22.17 |
| June | 23.24 | 25.51 | 27.59 | 25.32 | 26.67 | 25.61 | 26.71 |
| July | 23.36 | 25.69 | 27.40 | 25.31 | 26.66 | 25.02 | 26.07 |
| August | 21.28 | 23.81 | 25.69 | 23.24 | 24.55 | 24.10 | 25.04 |
| September | 17.04 | 18.03 | 20.76 | 18.44 | 19.75 | 19.05 | 19.85 |
| October | 12.83 | 14.14 | 15.41 | 13.60 | 14.81 | 14.18 | 14.79 |
| November | 8.01 | 8.12 | 8.65 | 7.74 | 8.60 | 7.79 | 8.28 |
| December | 6.31 | 5.69 | 5.82 | 5.35 | 5.80 | 5.25 | 5.68 |
| $r^2$ | | 0.919 | 0.801 | 0.932 | 0.870 | 0.901 | 0.853 |
| MBE | | 0.336 | 1.570 | 0.130 | 1.087 | 0.149 | 0.928 |
| RMSE | | 1.545 | 2.550 | 1.401 | 2.012 | 1.808 | 2.147 |
| t - ist | | 0.747 | 2.591 | 0.320 | 2.131 | 0.282 | 1.591 |

monthly average daily total solar radiation changes per month from the horizontal surface for Aksaray province is shown in Figure 3.

## RESULTS AND DISCUSSION

Tomato samples of Herkul F1 (SF/03) cultivated in Aksaray province were pre-processed and dried in a shelf-type dryer. During the test process, the temperature and humidity distributions of the dried products in the dryer, outdoor temperature and humidity, along with total solar radiation from the horizontal surface were continuously measured. Temperature and humidity change during the daytime in the dryer performed in the tomato drying experiments are given in Figure 4. The average atmospheric air temperature and relative humidity values during dry daylight hours were 49°C and 35%. The change in the inlet and outlet atmospheric air temperatures of the drying air and the solar radiation values on the system in the solar energy air heater is shown in Figure 5 and values. Results showed that the temperature of the dryer reached 56°C due to solar radiation and environmental conditions. It has been seen that the dryer can be brought to a better usable condition by implementing different designs on the dryer cover system, the shelf system and the absorber. It has also been seen that the shelf solar dryer provides a partial drying advantage over the open-air tomato drying. This advantage has been observed to provide a higher drying temperature in the dryer during daytime hours and a rapid weight loss in the lower shelves (Third and fourth shelves).

Considering the fact that the dried tomatoes in the shelf dryer protect from adverse environmental conditions such as rain, dust, etc, it has also been seen that they are cleaner than the open areas in terms of cleanliness. The tomato samples on the top shelf have been exposed to oxidative reactions causing changes in color by reacting with oxygen in the air because they dry up longer and lose moisture more slowly. The temperature in the drying air has changed depending on the drying period and it has been observed that there is decrease in the temperature of the drying air and the increase in the elongation and discoloration of the drying time.

As a result, it is recommended to use solar

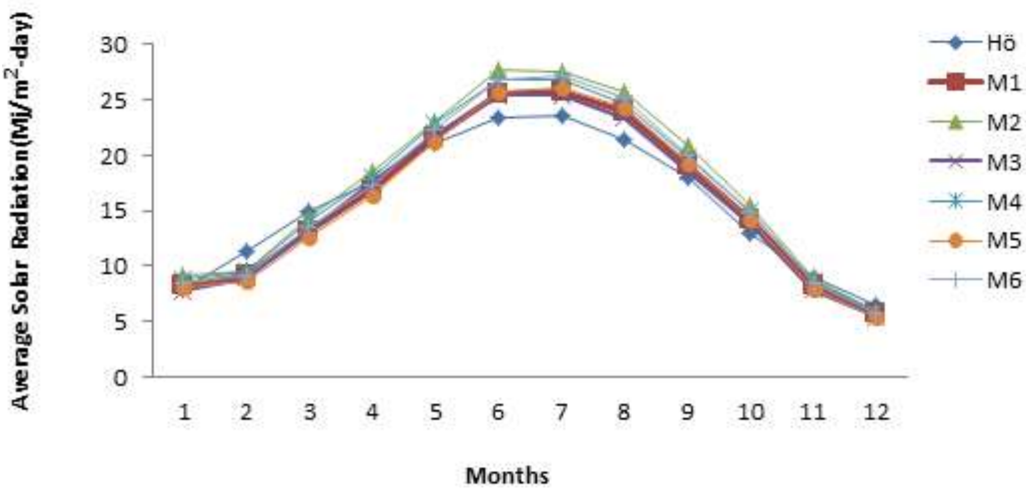


**Figure 3.** Comparison of measurement and estimation values for Aksaray province by models.

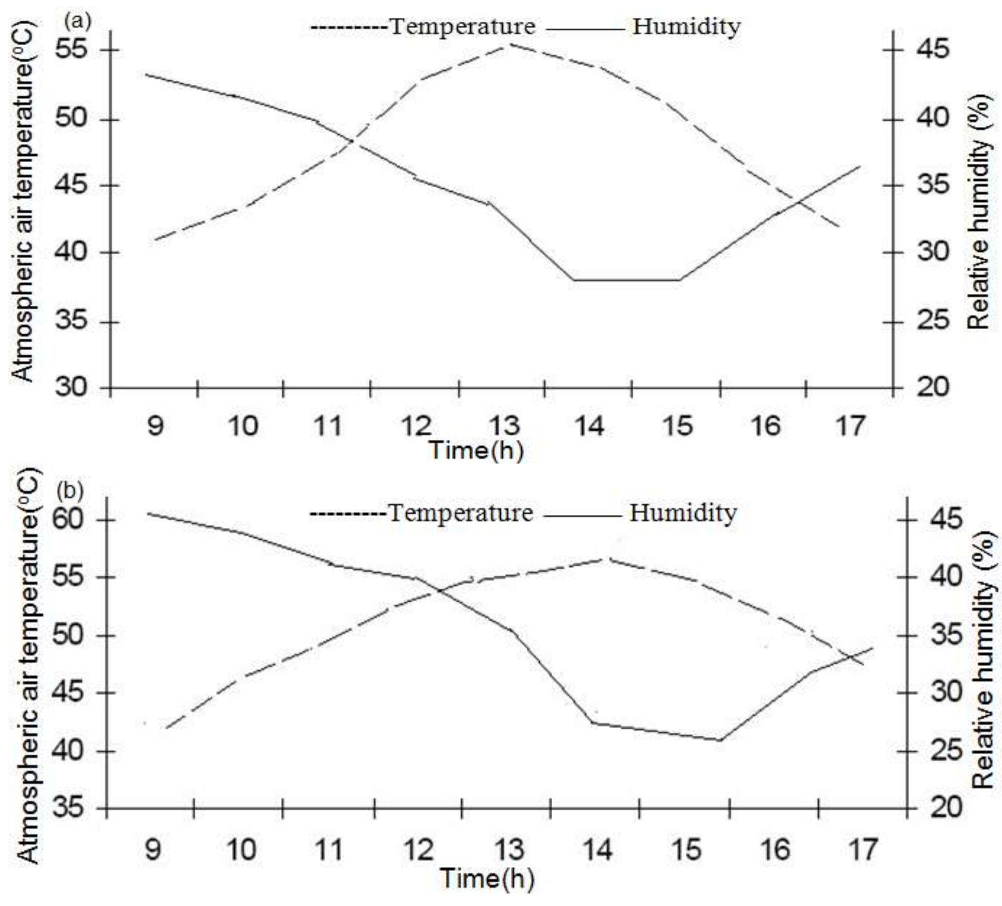


**Figure 4.** Change in dryer temperature (a:24.07.2017, b:25.08.2017) in the tomato drying experiments.

energy shelf dryers in Aksaray province conditions. Instead of using only 10 pieces shelves, it is recommended to use 2-3 shelves when considering color formation and drying speed. In addition, an additional heater can be placed in the lower part of the drying chamber where the shelves are located so that the nights

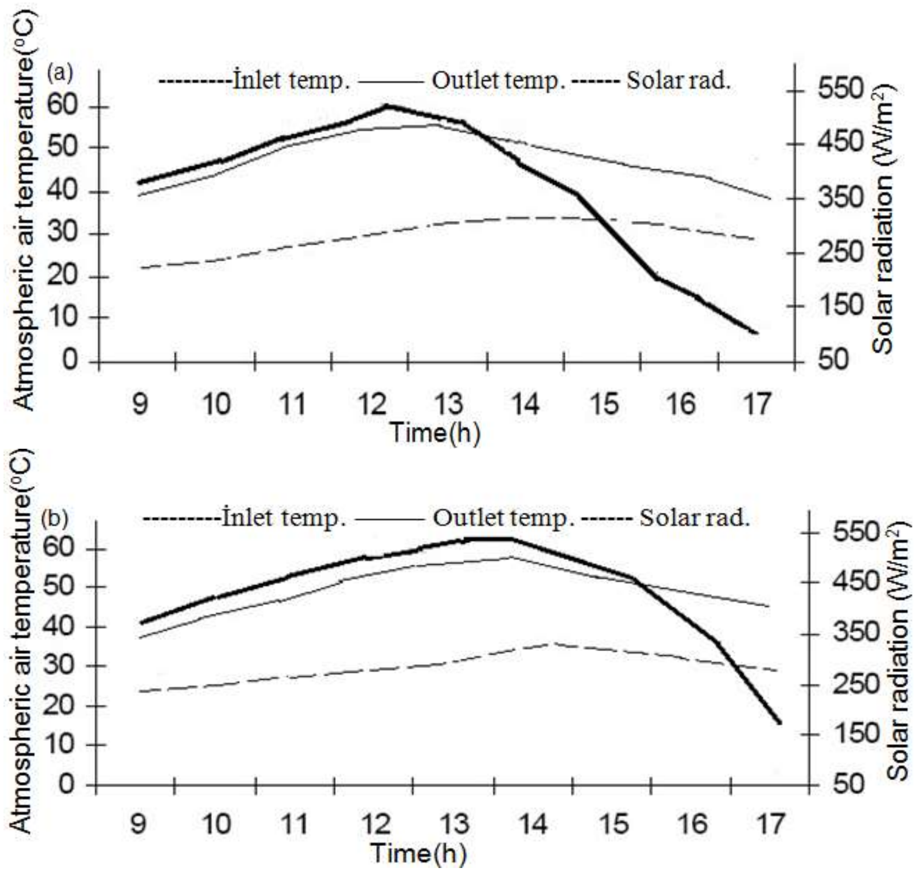


**Figure 5.** Change of air heater operating parameters in tomato drying experiment (a:24.07.2017, b:25.08.2017).

can continue to dry. Six different models along with MBE, RMSE and t-stat comparison methods were used to calculate the amount of global solar radiation on the horizontal surface. When a general evaluation was made between all equations according to all three comparison methods, the best results were given by Model-3 with values of MBE=0.130 and RMSE=1.401, while the best result from t-statistics was with t-ist=0.282 with Model-5. When the equations are evaluated statistically, it has been shown that the solar family type shelf dryer and tomato drying conditions can be used for Aksaray province if all the equations in the models are below the acceptable t- critical=3.106 value at α=0.01 statistical significance level.

## CONFLICT OF INTERESTS

The author has not declared any conflict of interests.

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