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Research Article

Drying of Apricot Using Ambient Air, Solar Water Collector Assisted Drying System and Solar Air Collector Assisted Drying System

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ABSTRACT
Food can be dried and stored safely. There are many different methods developed for drying. By drying, the amount of free water in the food is reduced and microbial growth can be stopped or slowed down completely. Since the volume of the dried product decreases, the storage volume decreases, and transportation becomes easier. One of the most used methods in drying is drying with solar energy. In this study, apricots were dried in a cabin type dryer. Three different types of drying cabinets were used experimentally to dry the products. The dried products were weighed for a certain period of time and the drying rate was controlled. The relative humidity and temperature values of the air circulating in the drying cabinets were measured. In the study, it has been observed that the drying cabinet supported by the air collector is much more efficient than the others. It has been seen that the drying process took about 75 hours for ambient air drying system, about 50 hours for solar water collector assisted drying system and about 35 hours for solar air collector assisted drying system. The effective moisture diffusion coefficient (D_{eff}) was calculated as 4.59x10^{-6} m^2/s for drying system with ambient air, 7.83x10^{-6} m^2/s for solar water collector assisted drying system and 8.32x10^{-6} m^2/s for solar air collector assisted drying system.
Keywords: Apricot; Food Drying; Microbial Growth; Solar Energy

Kabin Tipi Kurutucularda Güneş Enerjisi ile Kayısı Kurutulması

ÖZ
Yiyecekler kurutulabilir ve güvenle saklanabilir. Kurutma için geliştirilmiş birçok farklı yöntem vardır. Kurutma ile gıdadaki serbest su miktarı azaltılır ve mikrobiyal büyüme durdurulabilir veya tamamen yavaşlatılabilir. Kurutulan ürünün hacmi azaldığı için depolama hacmi azalır, nakliyesi kolaylaşır. Kurutmada en çok kullanılan yöntemlerden biri güneş enerjisi ile kurutmadır. Bu çalışmada kayısılar kabin tipi kurutucuda kurutulmuştur. Ürünlerin kurutulmasında deneysel olarak üç farklı tipte kurutma kabini kullanılmıştır. Kurutulan ürünler belirli bir süre tartılarak kuruma hızı kontrol edilmiştir. Kurutma kabinlerinde dolaşan havanın bağıl nem ve sıcaklık değerleri ölçülmüştür. Çalışmada hava kollektörü ile desteklenen kurutma kabininin diğerlerine göre çok daha verimli olduğu gözlemlenmiştir. Kurutma işleminin ortam havası kurutma sistemi için yaklaşık 75 saat, güneş enerjili su toplayıcı destekli kurutma sistemi için yaklaşık 50 saat ve güneş hava kollektörü destekli kurutma sistemi için yaklaşık 35 saat sürdüğü görülmüştür. Etkili nem difüzyon katsayısı (D_{eff}), ortam havası ile kurutma sistemi için 4,59x10^{-6} m^2/s, güneş enerjili su kollektörü destekli kurutma sistemi için 7,83x10^{-6} m^2/s ve havalı güneş kollektörü destekli kurutmasistemi için 8,32x10^{-6} m^2/s olarak hesaplanmıştır.
Anahtar Kelimeler: Kayısı; Gıda Kurutma; Mikrobik Büyüme; Güneş Enerjisi

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Introduction

Drying can be used for reducing the moisture content of 80-95% in fresh fruits and vegetables (Santos et al. 2022; Prosapio and Norton, 2018; Waghmare, 2021). In order to safe storage, final moisture content of the fruits and vegetables should be reduced to less than 20% and 10 % respectively (Afolabi, 2014). The drying process ensures that the dried product remains unspoilt for a longer time. The purpose of drying food is to remove the free water from the wet products and to stop the growth of biochemical reactions and microorganisms in the products. By drying, it is possible to reduce the volume and weight of the products. Thus, with drying, transport and storage costs can be reduced.

The drying process starts with the solution of the bonding forces between the water and the dry matter in the product. This requires a certain amount of energy. This energy must be continuously supplied to the drying material as heat energy. This heat evaporates the moisture present in the surface and pores of the layer to the air. In this sense, it may be said that drying is a mass and heat transfer process. In order to ensure the consumption of agricultural products such as vegetables, fruits and cereals outside the harvest seasons, drying is becoming more and more important. As the water activities of the foods can be brought to the desired values in the drying process, it becomes possible to store the dried products for a long time.

The purpose of drying for the food industry, is mainly to store fruits and vegetables for a long time without losing their nutritional value. The quality of the drying process depends on whether the dried product retains its colour, smell, taste, nutritional value and shape prior to the drying process. Another criterion is the ability to rehydrate. That is, when the dried product is put back in a humid environment, it can reach its original moisture content.

Solar energy is an abundant, continuous, renewable and free energy source. As a clean and free energy source, solar energy is one of the most common drying methods. Sun drying has some negative effects such as being open to pests, unwanted foreign substances such as dust, and soil, interruption of drying and prolongation of drying time in cases such as rain and extreme wind. Because of these negative effects, it is more advantageous to use solar dryers to eliminate the disadvantages of outdoor sun drying. The development of drying systems using solar energy is also important for food quality and cleanliness of the products. Reliable drying air temperature for agricultural products varies between 35°C-77°C. This is an important point in the design of solar energy systems (Orikasa et al. 2008; Simal et al. 2005; Korese and Achaglinkame, 2022).

A sun dryer consists of a heater in which solar energy is collected in terms of structure and storage areas where the material to be dried. In some dryers, the heater and the storage are made as a whole, but they are often separate from each other. However, no matter which type dryer used, the material to be dried is completely isolated from the external environment and drying is provided in closed places. The dryers that use the direct solar radiation, the sun-facing surface are made of glass or permeable plastic covers. Greenhouses that are idle in summer can be also used for drying, which can be considered as dryers that directly benefit from solar energy.

Cabin-type dryers can be considered as a heat box where fruits, vegetables and other agricultural products are dried in a tray. Its upper surface (the sun-facing surface) is covered with a transparent cover to get the solar radiation. The air usually enters the dryer from the bottom part, passes through shelves and left from the top of the dryer. One of the important feature for the solar dryer is the operating costs which are low and it can be made with local materials and workmanship. Figure 1 shows the cabin-type solar energy drying system used in this study.

Many studies have been done about drying of vegetables and fruits with solar energy. Timoumi et al. (2004) showed the thermal behaviour of a solar energy as an energy source for drying of foods. Vijaya Venkata Raman et al. (2012) gave information about solar drying technologies for food producer countries. They have done different designs, types and performance analysis for solar dryers. Belessiotis and Delyannis (2011) mentioned different indirect and direct solar dryers. Gallali et al. (2000) examined the solar drying of figs, grapes, onions and tomatoes by comparing the chemical and sensory analysis data.

Figure 1: Ambient air drying, solar water collector assisted drying and solar air collector assisted drying cabin-type dryers used for experiments in the study.

Mengeş (2001), studied the sour cherry and apricot grown in the Konya region and tried to decide to the drying characteristics of different air temperatures and air speed conditions. The air temperatures were 60 ºC, 70 ºC and 80 ºC, and air velocity were 1.0 m/s, 2.0 m/s and 3.0 m/s. The effect of air temperature and air speed on the drying rate of the products was determined. He stated that as the air temperature and speed increases for the drying, the amount of moisture away from the products increases and as a result, the drying time of the products is shortened.

Toğrul and Pehlivan (2002) examined the drying of apricot grown in Elazığ in a drying cabinet. They used the solar heater. The air heated in the solar air heater was passed through the drying cabinet. Changes in the mass and drying parameters of apricots in the cabinet were recorded daily during the experiment. The drying curves obtained from the data were adapted to a series of mathematical models and the effects of drying air temperature, velocity and relative humidity on the model constants and coefficients were evaluated by multiple regression. They reported that apricot, whose correlation coefficient (R^2) was 0.994, described the solar drying curve satisfactorily as compared to the previously given models.

Şahin and Öztürk (2016) carried out the process of drying unpeeled and sliced figs by osmotic dehydration.

Hacıseferoğulları et al. (2007) made a study on 6 apricot varieties. In this study, physical and chemical properties of apricot varieties were determined. In their study, Karabulut et al.2007 dried apricots with 50-60-70 and 80 °C temperature and examined the effects of drying temperature on color and β carotene levels of apricots. Al-Sebai. (2002) dried seedless grapes, figs, apples, tomatoes, onions and peas in the indirect solar energy-powered dryer. Gallali et al. (2000) evaluated the results of chemical and sensory analysis of grapes, figs, tomatoes and onions for solar drying and natural drying.

Pavon-Melendez et al. (2002) in their study, dried mango slices and developed a dimensional analysis for detailed equations of heat and mass transfer during drying. Krokida et al. (2003), have carried out some studies on the drying of potatoes, carrots, peppers, garlic, onions, mushrooms, corn, peas, celery, squash and tomatoes.

Materials and Methods

This study was carried out in the Clean Energy House with three type solar dryer systems (Figure 2), located between the 37º46 'north latitude and 29º06' east longitude within the campus area of Pamukkale University.

Fig. 3 and Fig. 4 illustrate the drying system. Cabinet type dryers are assembled at a fixed angle of 45 ° in accordance with the latitude of Denizli province where the study is carried out. There are 3 types of drying cabinets. One of the cabinet-type dryers is supported by a solar air collector (Figure 3-a), the other cabin type is drying with hot air taken from directly from the environment (Figure 3-b). Another cabinet is supported with a solar water collector (Figure 3-c). Working with solar water collector; provides heating of the ambient air in the solar water collector and then air is heated through the air/water heat exchanger, and heated air sending inside the drying cabinet. The other two cabinets are separated from each other by means of a valve. In this way, one of the cabinets performs the drying process by sending only the ambient air through the shelves and the other cabinet is supported with a solar air collector. In this dryer, environmental air passed through the solar air collector and after heated in the solar air collector, it sends into the cabinet. In this way, three different drying system has been studied and results were compared.

The drying process was carried out in the drying cabinets shown in Figure 4. Experiments were carried out during 12-15 June 2016. The apricots to be used in the experiments were obtained from the market. Apricots with masses close to each other were selected and used in drying process. The geometric mean diameter of wet apricots was assumed to be about 60 mm (Ozturk and Sahin, 2018a). However, the average weight of fresh apricots was measured to be about 37 g. Before drying, the initial moisture content of the wet apricots was measured to be about 81% (wet basis). Fresh apricots were placed on a 50 cmx70 cm perforated shelf inside the drying cabinet. Throughout the drying process, the weights of the apricots were measured with precision scales and the drying process was continued until the final moisture content of the apricots was about 19% (wet basis). In addition, the temperature and humidity values in the drying chamber were measured during the drying process using a moisture meter and a thermocouple.

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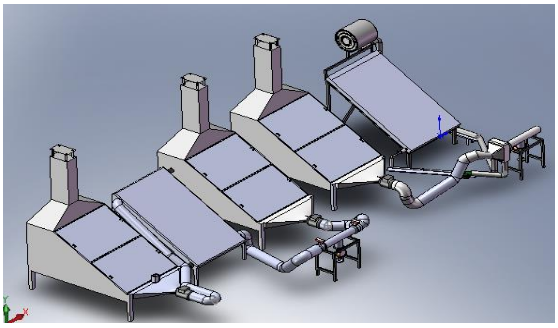

Figure 2. Ambient air drying, solar water collector assisted drying and solar air collector assisted drying cabin type dryers connections

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Figure 3. Laying food products in a solar drying system

2.1. Drying Kinetics

Moisture content of apricots during drying (*MR*) can be calculated with Equ. (1) (Doymaz, 2005).

$$MR = (M - M_e)/(M_o - M_e) \tag{1}$$

Here; M indicates the moisture content at any time (kg/kg), M_o the initial moisture content (kg/kg) and M_e the moisture content at the time of equilibrium (kg/kg). Due to forced convection, the value is neglected in the calculations and the moisture content (*MR*) may be written as simplified as in Equ. (2).

$$MR = M/M_o \tag{2}$$

The moisture content of apricots during drying was compared with 10 different drying models was shown in Table 1. The regression coefficient (R^2) is calculated by calculating the square root of the mean error (RMSE) and the reduced chi-square (Ɣ^2) values.

Regression coefficient (R^2), square root of error mean (RMSE) and reduced chi-square (Ɣ^2) values can be calculated by the following equations. Determination of the model closest to the experimental data is determined according to the criterion that R^2 is the highest RMSE and Ɣ^2 is the lowest.

$$R^2 = \frac{\sum_{i=1}^{N}\left(\left(MR_{deneysel\ ,i} - \overline{MR_{deneysel\ ,i}}\right)^2 - \left(MR_{tahmin\ ,i} - MR_{deneysel\ ,i}\right)^2\right)}{\sum_{i=1}^{N}\left(MR_{deneysel\ ,i} - \overline{MR_{deneysel\ ,i}}\right)^2} \tag{3}$$

$$RMSE = \sqrt{\frac{\sum_{i=1}^{N}\left(MR_{deneysel\ ,i} - MR_{tahmin\ ,i}\right)^2}{N}} \tag{4}$$

$$\chi^2 = \frac{\sum_{i=1}^{N}\left(MR_{deneysel\ ,i} - MR_{tahmin\ ,i}\right)^2}{N - n} \tag{5}$$

Figure 4. Solar drying system. a) Air type solar collector supported. b) Working with ambient air. c) Water type solar collector supported.

Table 1. Drying models used for moisture content of apricots

Model Number	Drying Model	Model Equations
1.	Lewis	$MR = exp(-kt)$
2.	Page	$MR = exp(-kt^n)$
3.	Modified Page	$MR = aexp[-(kt^n)]$
4.	Henderson and Pabis	$MR = aexp(-kt)$
5.	Logarithmic	$MR = aexp(-kt) + c$
6.	Binomial	$MR = aexp(-k_o t) + bexp(-k_1 t)$
7.	Two-term	$MR = aexp(-kt) + (1-a)exp(-kat)$
8.	Wang and Singh	$MR = 1 + at + bt^2$
9.	Verma et al.	$MR = aexp(-kt) + (1-a)exp(-gt)$
10.	Weibull distribution	$MR = a - bexp[-(kt^n)]$

Source: (Doymaz, 2005; Babalis et al. 2006; Mujic et al. 2014; Ozturk et al. 2018)

Here; experimental $MR_{deneysel,i}$ moisture rate, $\overline{MR_{deneysel,i}}$ average of experimental moisture rate, $MR_{tahmin,i}$ estimated humidity rate, n the number of constants in the drying model and N the number of experimental data.

The effective moisture diffusion coefficient (D_{eff}), which is one of the important parameters in drying kinetics, is equal to Eq. (6) which is obtained from the slope of the logarithm of the moisture content over time (Ozturk and Sahin 2018b).

Here; the radius of the product and the drying time. In this study, it has been assumed that the geometric shape of dried apricots is spheres and the diameter of the product during drying is 60mm. Spouse. (6) by regulating the effective moisture diffusion coefficient Eq. (7) (Ozturk and Sahin, 2018a).

Here; d_e the diameter (m) of the product and D_{eff} the effective moisture diffusion coefficient (m² / s).

$$ln(MR) = ln\left(\frac{6}{\pi^2}\right) - \frac{\pi^2 D_{eff}}{r^2}.t \quad 6$$

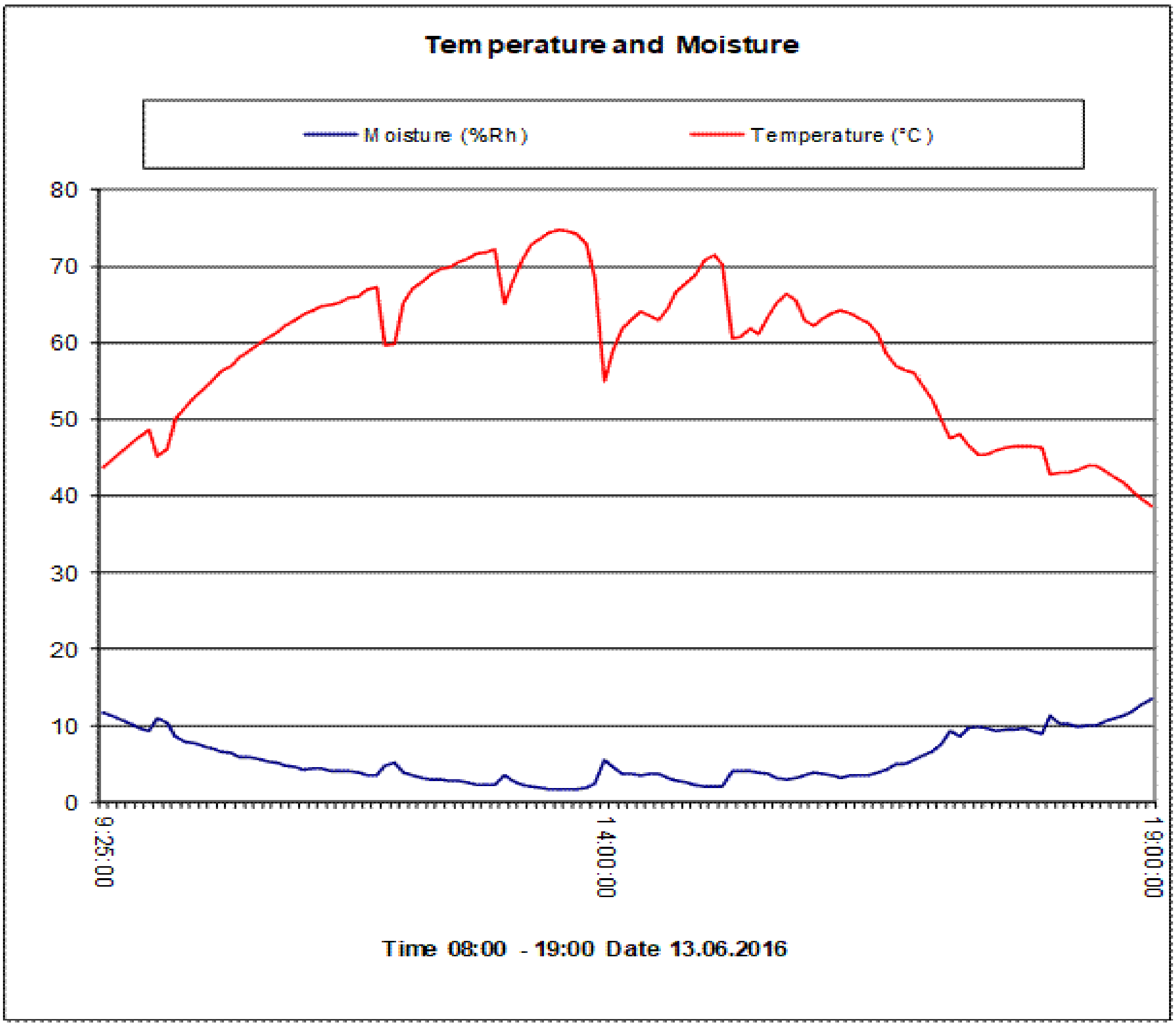
$$D_{eff} = \frac{(d_e/2)^2}{\pi^2} \cdot \frac{\partial(\ln(MR))}{\partial t} \quad 7$$

Result and Discussion

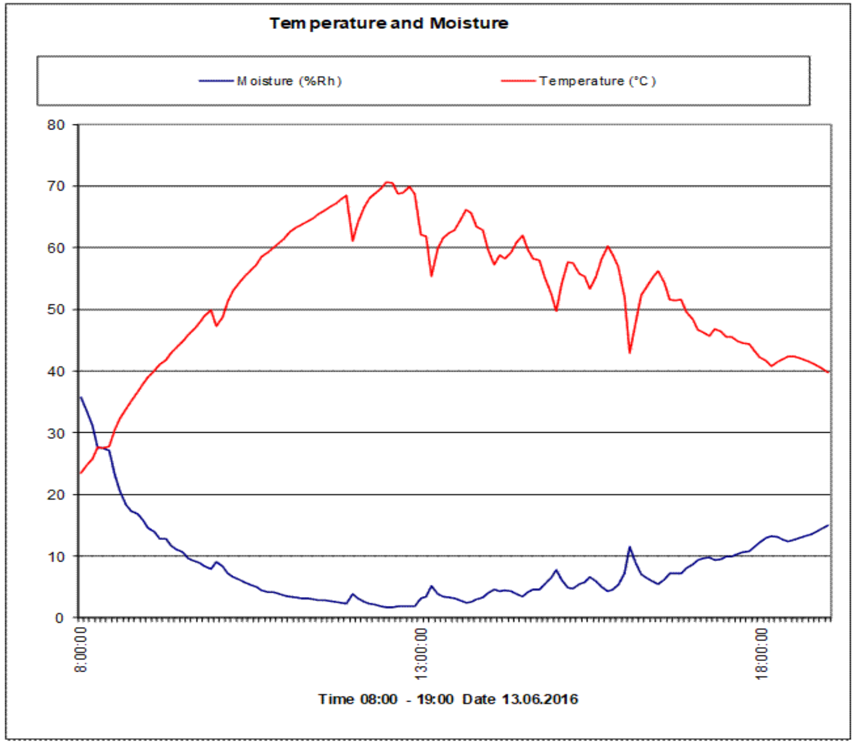
Apricots are dried in 3 different types of solar drier as described above and the results are given below. Figure 5 shows the change in temperature and humidity during the day for 3 different drying cabin types. As can be seen from Figure 5, the highest temperature is in the solar air collector supported cabinet dryer, while the lowest temperature is in the collector operating with ambient air. At the same time, the lowest humidity measured in the cabin was in the solar air collector assisted cabinet, while the highest humidity occurred in the cabinet with ambient air drying.

Variation of the moisture content and temperature of air during drying of apricots for different type dryers (ambient air, solar water collector assisted drying system and solar air collector assisted drying system) are given in Figures 6, 7 and 8, respectively. For all three systems, the drying process was completed when the final moisture content of apricots reached about 19%. Accordingly, the drying process took about 75 hours for ambient air-drying system, about 50 hours for solar water collector assisted drying system and about 35 hours for solar air collector assisted drying system.

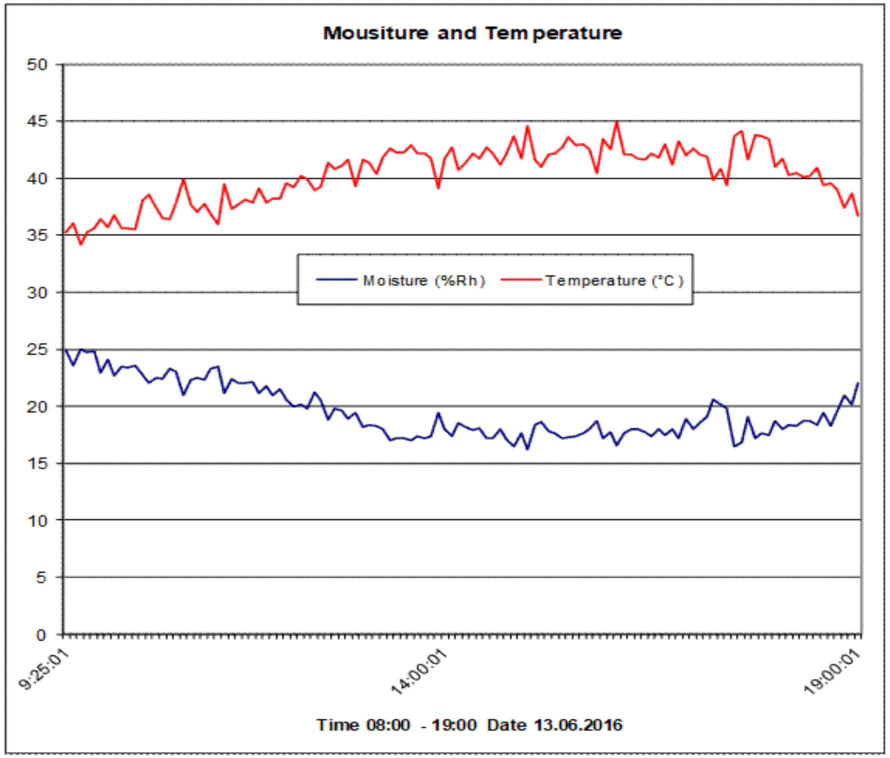
The variation of the moisture content given in Figures 6, 7 and 8 during drying was tested with the drying models given in Table 1 and the results are given in Table 2. The results show that the Weibull distribution model is the model that gives the closest results to the experimental moisture content data.



a. Solar air collector assisted drying system



b. Solar water collector assisted drying system



c..Ambient air drying system

Figure 5. (a,b,c) Variation of temperature and humidity for three different dryer cabinets

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In order to calculate the effective moisture diffusion coefficient, *ln* (*MR*) -time relationship is given in Figure 9 for 3 different drying systems. The slope of ln (MR) respect to time as given in Eq. (6) is -0.0503 for ambient air-drying system, -0,0858 for solar water collector assisted drying system and -0.0912 for solar air collector assisted drying system. When obtained slope substitute in Eq.(7), the effective moisture diffusion coefficient (D_{eff}) can be calculated as 4.59x10^{-6} m^2/s for drying system with ambient air, 7.83x10^{-6} m^2/s for solar water collector assisted drying system and 8.32x10^{-6} m^2 / s for solar air collector assisted drying system.

Table 2. Equation coefficients and statistical results of mathematical models obtained for apricot drying.

Model Name	Model Constant	R^2	*RMSE*	χ^2
Lewis	$k = 0.0417$	0.9759	0.0440	1.99E-03
Page	$k = 0.0507, n = 0.9408$	0.9775	0.0425	1.91E-03
Modified Page	$a = 1.0320, k = 0.0602, n = 0.8992$	0.9780	0.0420	1.93E-03
Henderson and Pabis	$a = 0.9848, k = 0.0409$	0.9763	0.0437	2.02E-03
Logarithmic	$a = 0.9798, c = 0.0087, k = 0.0420$	0.9763	0.0436	2.08E-03
Binomial	$a = 0.9835, b = -2.47E-05, k_0 = 0.0407, k_1$=-0.0775	0.9763	0.0436	2.14E-03
Two-term exponential	$a = 0.4887, k = 0.0616$	0.9771	0.0429	1.95E-03
Wang and Singh	$a = -0.0310, b = 2.58E-04$	0.9504	0.0632	4.22E-03
Verma et al..	$a = 0.9022, g = 0.1599, k = 0.0379$	0.9783	0.0418	1.91E-03
Weibull distribution	$a = -0.0754, b = -1.1199, k = 0.0679, n = 0.8202$	0.9791	0.0410	1.89E-03

Source: Ozturk et al. 2018.

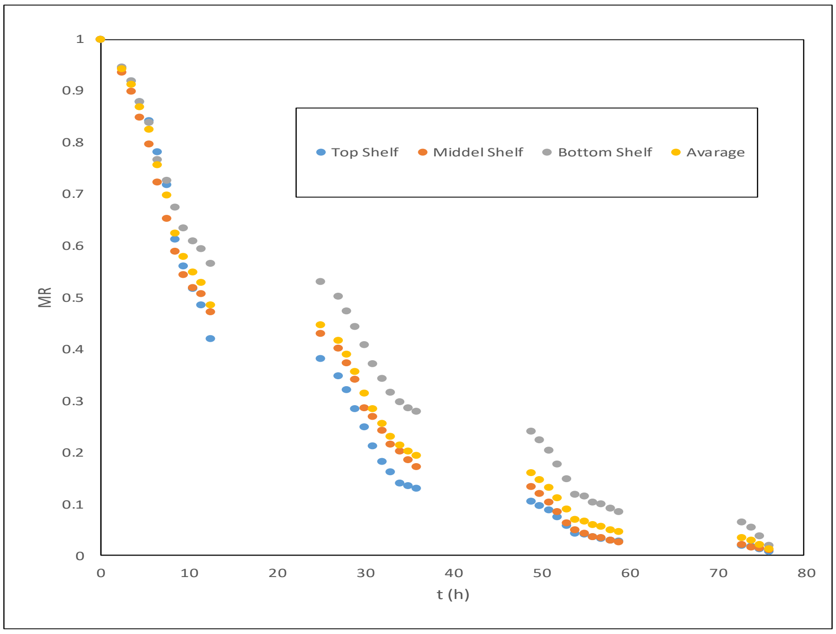

Figure 6. Variation of MR with time for ambient air drying system

In the literature, in recent studies for drying of apricot using different drying techniques, effective moisture diffusion coefficient values was calculated as $1.62x10^{-9}$-$4.36x10^{-9}$ m²/s (Faal et al. 2015), $2.37x10^{-9}$-$6.23x10^{-9}$ m²/s (Kayran and Doymaz, 2017) and $6.75x10^{-10}$-$2.56x10^{-9}$ m²/s (Horuz et al. 2017) were found to be in the range. Therefore, it can be said that the results of this study are consistent with the values in the literature.

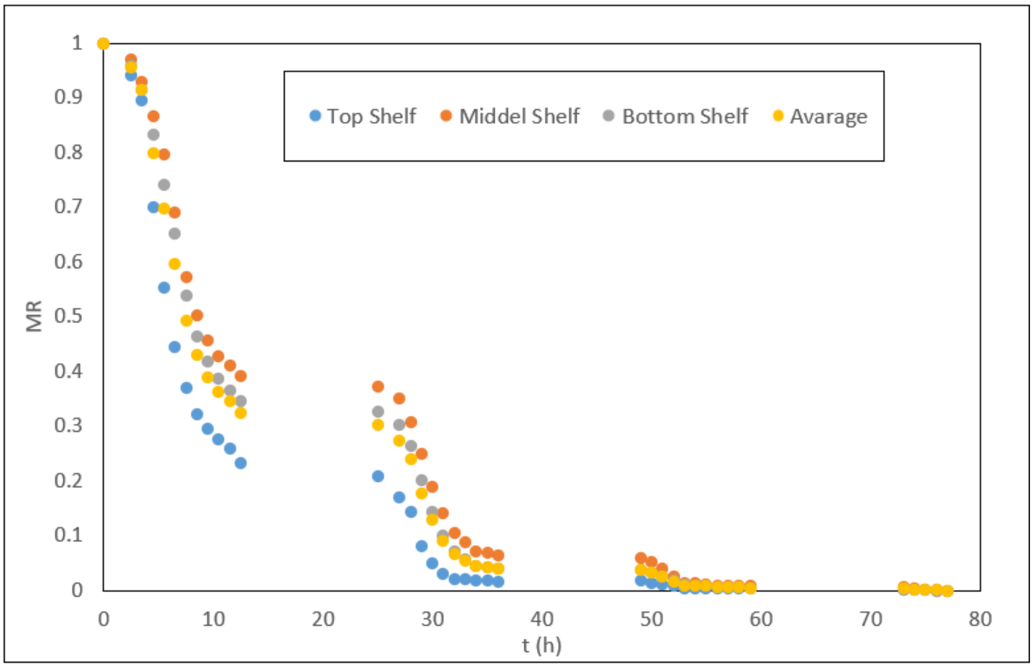

Figure 7. Variation of MR with time for solar water collector assisted drying system

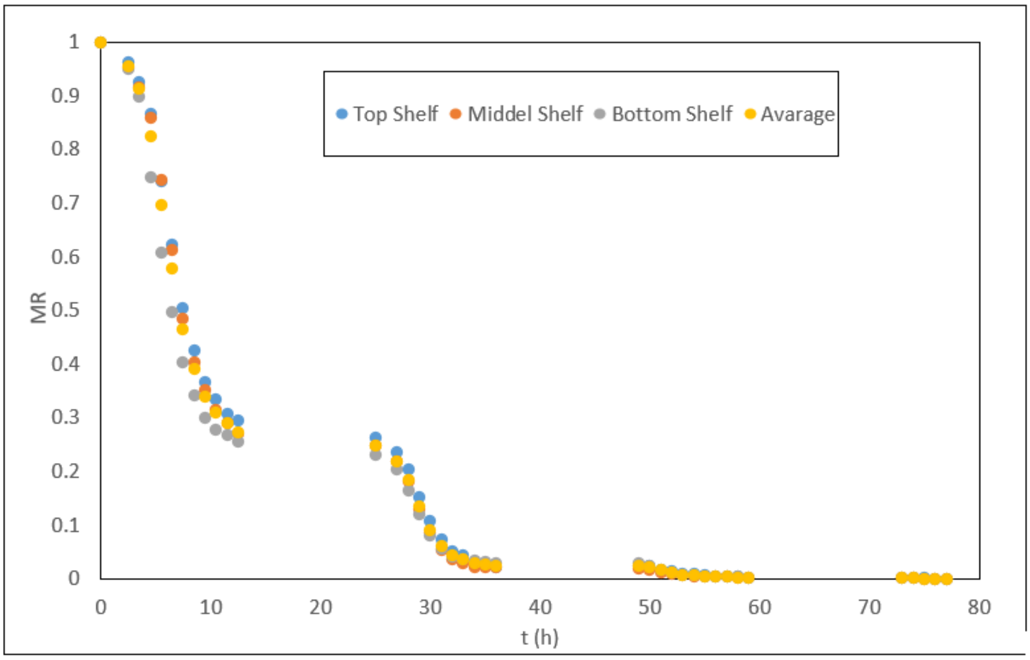

Figure 8. Variation of MR with time for solar air collector assisted drying system

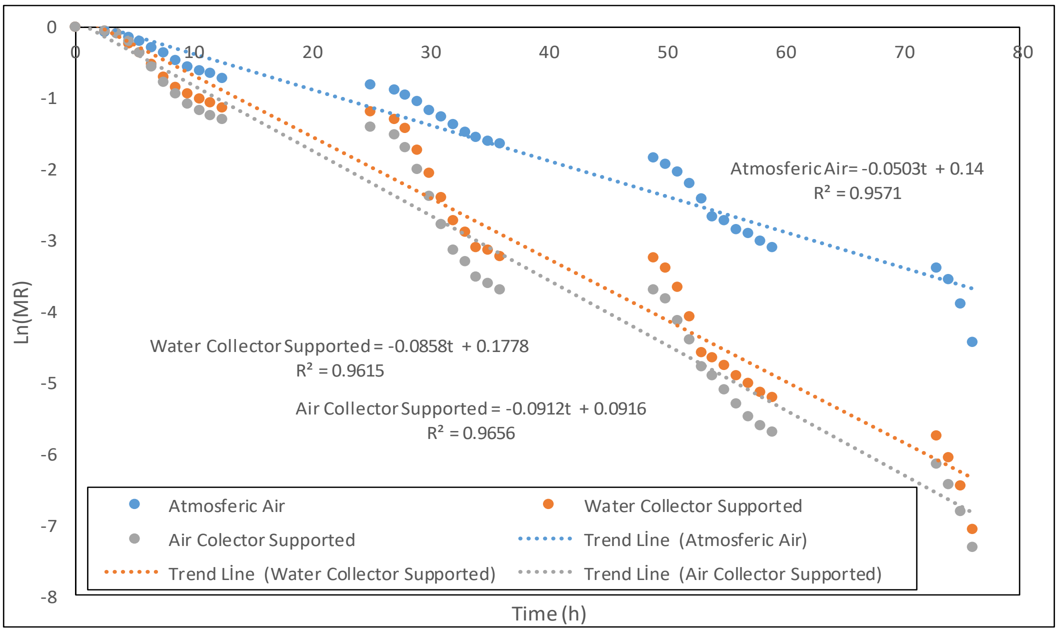

Figure 9. Relationship between Ln (MR) and drying time linear equation for different drying systems

Conclusion

Within the scope of the study, the efficiencies of different types of sun drying systems were experimentally studied for drying apricots in 3 different sun drying systems. The results of the study were reported the effect of using different types of solar energy systems on drying times. In the study, the change in moisture content of the products on the shelves in the drying cabinet was also studied.

At the end of the study, it was observed that drying was the slowest in the case of drying by passing atmospheric air through the cabinet. On the other hand, even if there is a very small difference between them, the air collector supported solar energy drying system can dry the apricot faster than the water collector supported solar energy drying system.The results of the study is agree with the studies in the literature. Tugrul and Pehlivan (2002), in their study, dried apricots by laying them in the sun and applying different airflow rates in the cabin. The results revealed that drying by laying in the sun is the slowest, and the drying rate increases as the air flow rate increases. Drying kinetics are also discussed in the study. Stegou–Sagia and Fragkou (2018) also dried apricots at 50, 60 and 70 °C temperatures and 0.5, 1, 1.5 and 2 m/s speeds with a solar drying system and reduced the moisture content of apricots from 80% to 10%. It has been observed that the drying time is shorter at high operating speeds and high temperatures.As a result, it has been observed that the drying cabinets supported by air collectors shorten the drying time for drying of fruits. In addition, it would be appropriate to change the shelves during drying, as the lower shelves dry out in a shorter time than the upper shelves.

Notes:

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