Süleyman Demirel Üniversitesi
Fen Bilimleri Enstitüsü Dergisi
Cilt 27, Sayı 2, 305-312, 2023

Süleyman Demirel University
Journal of Natural and Applied Sciences
Volume 27, Issue 2, 305-312, 2023

DOI: 10.19113/sdufenbed.1237480

Determination and Mathematical Modeling of Drying Kinetics of Avocado Slices by Tunnel Type Solar Drying and Microwave Drying Method

Sevil KARAASLAN*[1], Kamil EKİNCİ[2]

[1]Isparta University of Applied Sciences, Faculty of Agriculture, Department of Agricultural Machinery and Technologies Engineering, 32200, Isparta, Türkiye

(Alınış / Received: 17.01.2023, Kabul / Accepted: 16.03.2023, Online Yayınlanma / Published Online: 25.08.2023)

Keywords
Avocado,
Solar tunnel dryer,
Microwave,
Modeling

Abstract: Within the scope of this study, drying studies of avocado fruit using a tunnel type solar dryer was experimentally carried out in Isparta conditions. At the same time, avocado slices were dried in household microwave assisted convective drier. In the study, avocado fruits were studied at 4 mm slice thickness. Also, time dependent moisture content, drying rate and drying characteristics of avocado slices are reported. Avocado fruits with an initial moisture content of 71.51±0.35% (on a wet basis) were dried both by solar tunnel drying and by microwave methods until their moisture content was 14.23±0.16% (on a wet basis). Drying processes took approximately 3 days for avocados with 4 mm slice thickness in the solar powered system. In the microwave dryer, dehydration times were founded as 76, 34 and 14 minutes, respectively, at 180W, 360W and 540W microwave powers. The drying data got from the assays were modelled with 8 different model equations. While determining the best model equation, R^2, should be the largest; SEE, RMSE and χ^2 should be the minimum. In both drying methods, the most suitable dehydration model equation was founded as the Alibaş model equation.

Tünel Tipi Güneş Enerjili Kurutucu ve Mikrodalga Kurutma Yöntemi ile Avokado Dilimlerinin Kuruma Kinetiğinin İncelenmesi ve Matematiksel Modellenmesi

Anahtar Kelimeler
Avokado,
Güneş enerjili tünel tipi kurutucu,
Mikrodalga,
Modelleme

Öz: Bu çalışma kapsamında, tünel tipi güneş enerjili kurutucu ile Isparta şartlarında avokadonun kurutma denemeleri deneysel bir şekilde gerçekleştirilmiştir. Ayrıca avokado dilimleri ev tipi mikrodalga destekli konvektif kurutucuda kurutulmuştur. Denemelerde avokado meyveleri 4 mm dilim kalınlıklarında çalışılmıştır. Bunlara ek olarak, avokado dilimlerinin zamana bağlı olarak nem içeriği, kuruma hızı ile kuruma karakteristikleri rapor edilmiştir. İlk nem içeriği %71.51±0.35 (y.b) olan avokado meyveleri, hem tünel tipi güneş enerjili kurutma yöntemi ile hem de mikrodalga kurutma yöntemi ile nem içeriği %14.23±0.16 (y.b) olana kadar kurutulmuştur. 4 mm dilim kalınlığına sahip avokadoların güneş enerjili tünel tipi kurutma sisteminde kurutma işlemleri yaklaşık 3 gün sürmüştür. Mikrodalga kurutucuda kurutma süreleri 180W, 360W ve 540W mikrodalga güçlerinde sırasıyla 76, 34 ve 14 dakika olarak bulunmuştur. Denemelerden elde edilen kurutma verileri, 8 farklı matematiksel model eşitliğe uygulanmıştır. En iyi model eşitliği belirlerken, R^2'nin en büyük, SEE, RMSE ve χ^2'nin en küçük olması gerekmektedir. Her iki kurutma yönteminde de, en uygun kuruma modeli, Alibaş model eşitliği olarak bulunmuştur.

1. Introduction

Avocado is a perennial herb from the (*Persea americana Mill.*) *Lauraceae* family. Avocado originating from Central America is grown in many countries, including Turkey, in semi-tropical and tropical regions [1]. Avocado is a tropical fruit with a rich nutritional component and important oil ingredient. Avocado typically has a smooth texture, buttery consistency, and rich flavor, unlike most fruits that are sweet or acidic [2]. The limited cultivation areas, high nutritional value and unique taste of avocado are its main economic features. Although its homeland is Central Mexico, it is also grown in different countries such as Indonesia, the United States, Brazil, Colombia and Turkey [3]. Avocado,

** Corresponding author: sevilkaraaslan@isparta.edu.tr*

which grows in tropical and semi-tropical regions, is a type of fruit that does not like too much cold. For this reason, avocados are not grown in every region and many countries meet their avocado needs from other countries [1]. Due to the availability of regions with suitable climates for avocado harvest and the high selling price in the market, avocado cultivation in Turkey is rising day by day. Avocado fruit production, which exceeded 5.5 million tons in 2016, has risen rapidly in the recent twenty years in the world. With this increased production, consumption has also increased. The most important reason for the increased consumption is that the fruit is rich in proteins, lipids, carotenoids, vitamins, fibers, unsaturated fatty acids and polyphenols [4]. In recent years, new areas where avocados are used on a global level have also been created [3]. Considering avocado production, there are a limited number of products (avocado oil, avocado puree, avocado juice, etc.) in the market. Therefore, there is significant potential for developing new products from avocados [1]. Avocado fruit can be consumed raw or cooked, as well as in many different processed forms. One of them is the drying process. Quality properties such as color, texture, gloss and porosity are adversely affected in the drying of avocados. Fruit flesh is washed and separated from the peel and seeds and is dried by different methods [5]. For this purpose, spray drying and drum drying techniques are mostly used. In addition, microwave, high pressure, pulsed electric field and ultrasound applications are also available to improve the quality and shelf life of freshly cut avocados.

Drying is the best protection technique used to preserve the quality and stability of harvested crops, to prevent decay and chemical deterioration caused by microorganisms, and to provide a longer shelf life.

In its shortest definition, drying can be expressed as "removal of water from the product". With drying, the mass and volume of the product are reduced, and at the same time, it provides convenience during storage, packaging, transportation and transportation processes [6]. The purpose of drying is to obtain products with good color, aroma and taste with low energy consumption in the shortest possible time. The method of drying in the sun in the open area is the oldest known drying method. In this method, the products are dried for a very long time, very large areas are needed for drying, the labor requirement is high, micro molds occur on the product and the product is exposed to dust, insects, birds and other microorganisms due to drying in the open area.

For this reason, many drying methods such as solar tunnel, convective, microwave, vacuum, infrared, fluidized bed, osmotic, spray and freeze drying have been developed since ancient times [7].

The solar drying technique used to dry many agricultural products has been used since ancient times. Passive solar cabinet dryers are mostly inexpensive units with simple construction and high applications used for domestic purposes. A solar tunnel dryer with an auxiliary fan, with a drying capacity of 25 kg/m^2, was tested in Indonesia for drying various agricultural products [8].

Microwave drying is based upon the principle of rapid dehumidification through the release of thermal energy through the vibration of water molecules in food.

With this method, it is possible to dry the products in a very short time compared to other methods [9]. Modeling the dehydration processing mathematically is a significant section of dehydration technology [10]. Mathematically modeling and simulating drying curves under various circumstances is highly significant for achieving more adequate studies. Based on this, various applications of mathematical modeling have been carried out to simulate post-harvest processes. Since the dehydration characteristics of each of the agricultural products are different from each other and vary according to drying conditions and methods, by modeling the drying process, we should be determined the drying kinetics. To date, many valuable studies have been performed with solar dryers used to dry various vegetables and fruits such as organic tomatoes, bananas, mint, grapes, tomatoes and apples as sources [11, 12, 13, 14, 15, and 16]. Although avocado is a fruit with high antioxidant activity, besides its high nutritional value, there are very few scientific studies on drying avocado fruits in the literature.

In this study, it was purposed to indicate the drying behavior of avocado fruit, to determine the optimum drying method at the final moisture values determined by tunnel type solar drying and microwave drying method. In addition, the mathematical thin layer drying model was determined by comparing eight different model equations that best describe it based on experimental data

2. Material and Method

The avocado fruit (*Persea americana Mill.*) used in the experiments was bought from a regional bazaar in Isparta (Turkey). The fruits were hand washed, dried with a towel and peeled. It was then cut into crescent-shaped slices of approximately 50 mm in diameter and 4 mm in thickness. The average initial moisture content of 3 repetitions of avocado slices of 50 grams dried in an oven was calculated to be 71.51±0.35 (w.b.) It was dehydrated until an ultimate moisture content of about 14.23±0.16 (w.b.) was reached.

2.1. Tunnel type solar dehydration of avocado slices

The solar powered tunnel dryer, which we used in the trial studies, was designed by Department of Agricultural Machinery and Technologies Engineering at Isparta University of Applied Sciences and installed on the department land (Figure 1).

This dryer has a drying tunnel where products are placed, a solar collector, an axial fan and a solar battery. The sections are all mounted on a metal counter. It has a black hexagonal channel solar collector, connected directly to the solar tunnel. In addition, the surface of the solar panels covered with a transparent polycarbonate film is 2 meters long and 1.9 meters wide. The solar cell module placed in the solar tunnel dryer is 150W to transfer the air through the fan carrier. The tunnel type solar dryers are arranged in parallel from east to west, facing South (Figure 1).

Figure 1. Solar dryer assembly

2.2. Microwave drying

The dehydration trials of avocados were performed using an Arcelik MD 594 (Turkey) microwave oven with a max. output of 800 W operating at 2450 MHz (12.24 cm wavelength) with specifications of 230 V, 50 Hz, and 2650 W. The microwave drier could be operated at five different microwave levels: 180, 360, 540, 720, and 900 W (Figure 2).

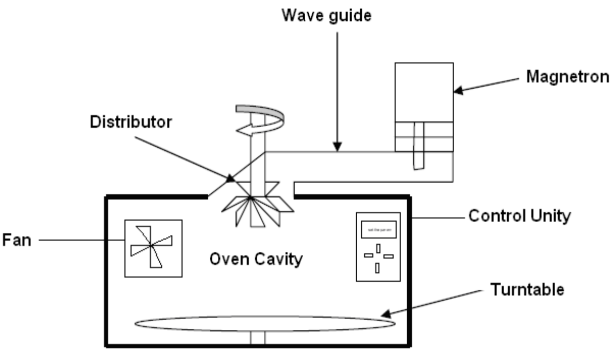

Figure 2. Schematic diagram of the microwave oven

The avocado slices out of the refrigerator were kept at room temperature for 2 h before they were dried in the microwave oven for the experiments. About 100 g of avocado slices were then weighed using an (Sartorius GP3202, Germany) electronic scale with an accuracy of 0.001 g. The dehydration stage was made real by drying sliced avocado samples with 180, 360, and 540 W microwave power. During the drying trials, each sample was located in the middle of the revolving glass plate of the microwave drier. Each experiment was carried out in 3 replicates in line with a predetermined schedule related to the microwave power and time. Finally, the average of the obtained results was taken.

2.3. Determination of moisture content, moisture ratio and drying rate

To calculate the initial moisture content of fresh avocado, 50 g fruit slices were dried in an oven at 105°C for 24 hours. Measurement of moisture content was made thrice and then averaged. The moisture contents (MR) of the dehydrated avocado slices were provided by calculating the following Equation (1).

$$MR = \frac{M_t - M_e}{M_0 - M_e} \quad (1)$$

The values in Equation 1 are respectively expressed as follows. MR is the moisture ratio (unitless), M_t is the moisture content of the sample at any given time (g water/g dry matter), M_e is the equilibrium moisture content (g water/g dry matter), and Mo is the initial moisture value (g water/g dry matter).

Due to the long drying times, the M_e value is quite small compared to the M_t and M_0 values. Therefore, the MR equation (M_t-M_e/M_0-M_e) has been simplified to (M_t/M_0) [17].

The drying rate is one of the most significant parameters in dehydration kinetics. The drying rate equation used to reveal the connection between the drying time and drying rate of the avocado fruit and was calculated using the formula below:

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

Expressing Equation 2 above, DR is the drying rate (g water/g dry matter min), M_t and M_{t+dt} are moisture contents at *t* and *t+dt*, respectively, and t is drying time (min) (18, 19).

2.4. Mathematical Modeling

Table 1 shows eight different mathematical models used for avocado moisture ratio in the literature. Statistical software Sigma Plot 12.0 was used to perform nonlinear regression analysis on the equation, and the drying parameters and coefficients (a, b, c, k, k1, k2, and n) of the equation were calculated. The determination of the best mathematical model was depending upon three statistical parameter of the correlation coefficient R^2 obtained by the non-linear analysis under different

Table 1. Model equations used for the solar tunnel drying microwave drying of avocado samples

Mathematical models		References
MR = exp(-kt)	Newton	[22]
MR = exp(-kt^n)	Page	[23]
MR = aexp(-kt)	Henderson and Pabis	[24]
MR = aexp(-kt) + c	Logarithmic	[25]
MR = aexp(-kt) + (1-a) exp(-kbt)	Diffusion	[26]
MR = aexp(-k(t^n)) + bt	Midilli et al.	[27]
MR = aexp((-kt^n) + (bt)) +g	Alibas	[28]
MR = a0 / (1 + aexp(kt))	Logistic	[29]

drying conditions, the chi-square value of χ^2, and the root mean square error (RMSE) (20). The lower the SEE, RMSE and χ^2 values and the higher the R^2 value, the better the goodness of fit (21). The equations of R^2, SEE, RMSE and χ^2 were given in (3), (4), (5) and (6), respectively:

$$R^2 = \frac{\sum_{i=1}^{N}\left(MR_{exp,i}-MR_{exp_{mean,i}}\right)^2-\left(MR_{pre,i}-MR_{exp,i}\right)^2}{\sum_{i=1}^{N}\left(MR_{exp,i}-MR_{exp_{mean,i}}\right)^2} \quad (3)$$

$$SEE = \sqrt{\frac{\sum_{i=1}^{N}\left(MR_{exp,i}-MR_{pre,i}\right)^2}{N-n_i}} \quad (4)$$

$$RMSE = \left[\frac{1}{N}\sum_{i=1}^{N}(MR_{pre,i} - MR_{exp,i})^2\right]^{\frac{1}{2}} \quad (5)$$

$$\chi^2 = \frac{\sum_{i=1}^{N}(MR_{exp,i}-MR_{pre,i})^2}{N-n_i} \quad (6)$$

MR_{exp} and MR_{pre} in equations 3, 4, 5 and 6 above are the experimental and predicted values of moisture content, respectively.

Additionally, z is the number of constants in the model and N is the total number of observations.

3. Results

Figure 3 indicates the panel inlet and outlet temperature as a function of drying time. The panel inlet temperature varied between 32°C and 40.7°C, and the panel outlet temperature varied between 43.3°C and 53.3°C. The representation of solar irradiance and air velocity as a function of time and days is given in figure 4. According to Figure 4, the velocity values were acquired from the fan and arrived at the summit approximately in the middle of the day. The solar cell drove the fan; therefore, the velocity of the airflow changed as a function of solar irradiation. Since the sun angles are variable throughout the day, solar radiation levels in the morning and afternoon were low.

The total dehydration time was recorded as 3120 minutes (approximately 3 days) in drying the avocado samples with a slice thickness of 4 mm in solar drying. Besides, drying times in microwave dryer at 180W, 360W and 540W microwave powers were determined as 76.34 and 14 minutes, respectively (Figure 5, 6). In Figure 5, the mean drying rate values of all drying methods are shown together. In Figure 6, only the mean drying rate values of the microwave drying method are given.

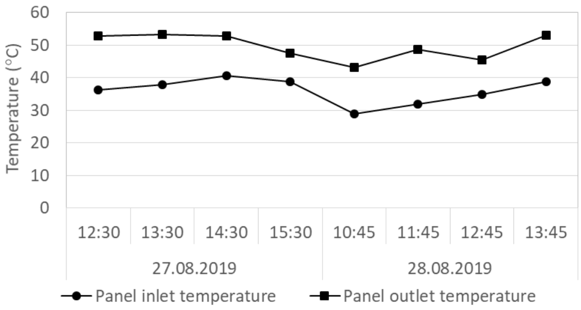

Figure 3. Panel temperature changing with time

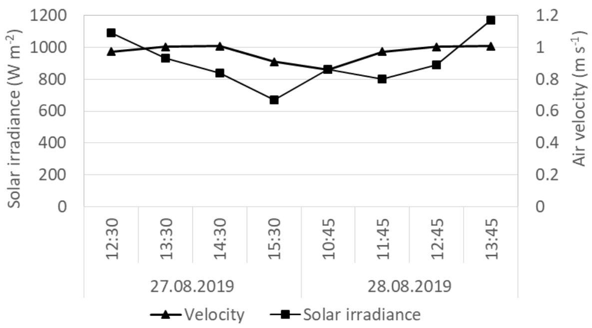

Figure 4. Solar irradiation and velocity values

When all the results are obtained from the point of total drying time, the shortest figured on total drying period (14 minutes) was attained with 540W microwave drying of 4 mm thick samples, while the longest (3120 minutes) was attained in the tunnel type solar dryer. This result showed that when the drying times of avocado samples dried with solar tunnel dryer and microwave were compared, the samples were more impressed by microwave power.

In the study of researcher (30) investigated the effects of microwave power (1500 W and 2100 W) and conveyor belt speed (0.175, 0.210 and 0.245 m/min) on drying time, color change and energy consumption in a microwave belt dryer of 5 mm thick sliced potatoes. According to their results, it was observed that energy consumption decreased with increasing microwave power and decreasing belt speed. In order

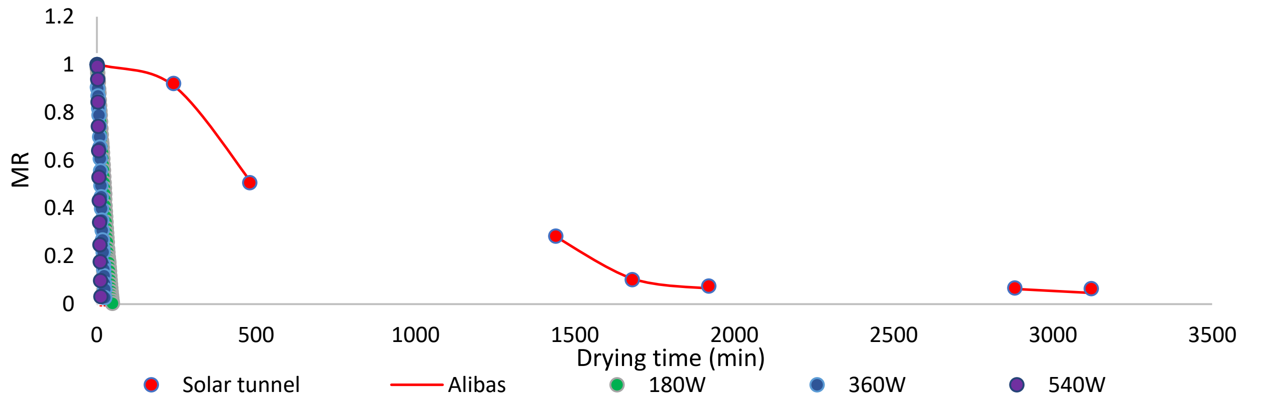

Figure 5. Moisture ratio versus drying time for avocado fruits under solar tunnel drier and microwave drier-corresponding best fitted model

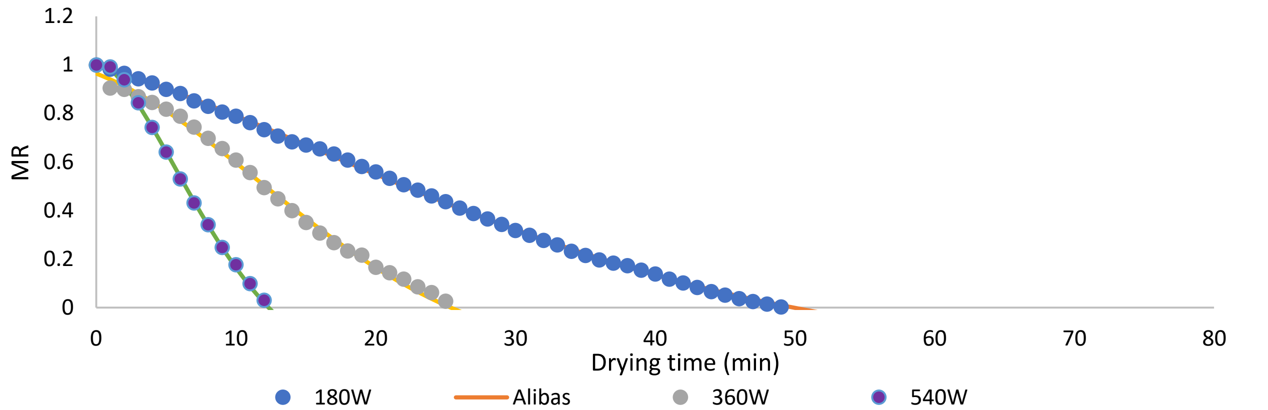

Figure 6. Moisture ratio versus drying time for avocado fruits under only microwave drier- corresponding best fitted model

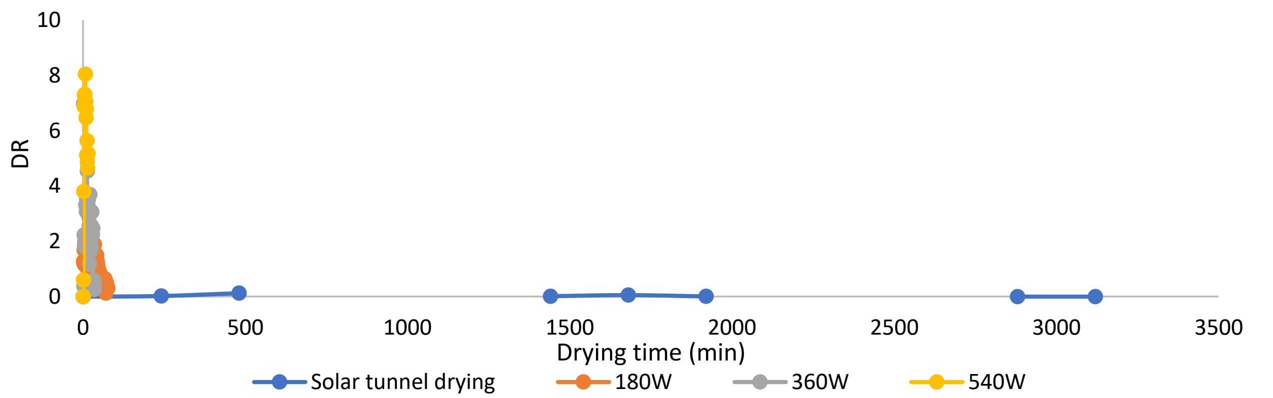

Figure 7. Drying rate curves of avocado dried at different microwave powers and tunnel type solar drying

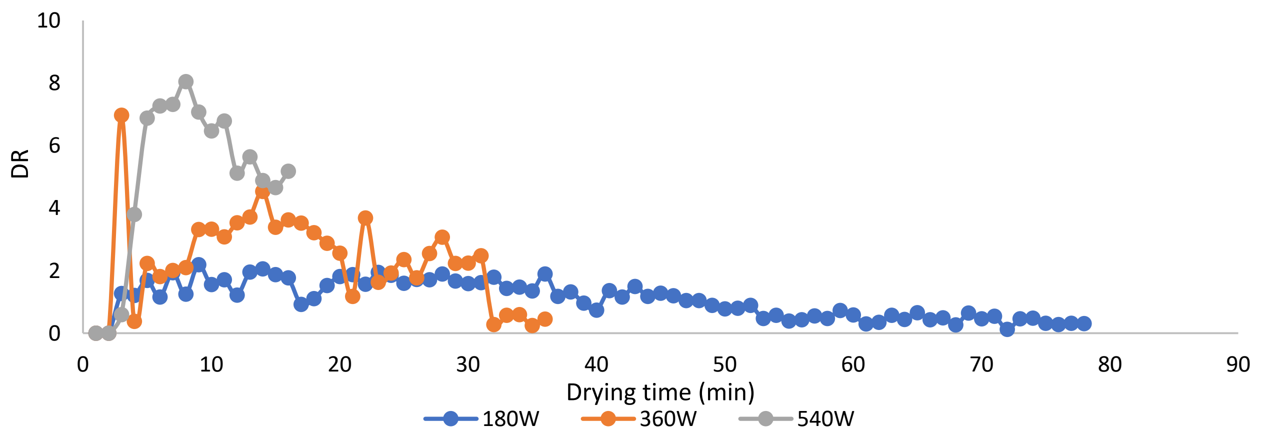

Figure 8. Drying rate curves of avocado dried at different microwave powers

to determine the suitability of nine drying models, correlation coefficient (r), standard error (es) and (χ2) were calculated by considering experimental and theoretical moisture ratios. They determined that the most optimal model for all drying conditions was the Page model. The drying rate curves obtained from the experimental data for microwave drying processes are given in Figures 7 and 8. In the microwave drying process, an increasing and then a decreasing rate period were obtained. Here, periods of progressive drying rate were explained as adaptation periods and can often be negligible. As a result of the experiments, it was found that the drying rate results increased when the microwave power values increased.

In another similar study, it was found that drying rates increased with increasing drying temperatures. At the same time, it has been reported that the drying rate increases with the increase in the evaporation rate occurring on the material surface during the constant rate drying phase of the drying. On the other hand, he stated that the moisture content, which decreases towards the end of the drying stage, becomes difficult to remove from the vegetable or fruit and therefore the drying rate decreases at this stage (31).

The drying data achieved from all drying methods were adjusted to the eight thin-layer drying model equations (Table 1). Table 2 indicates the statistical analysis inferences of all model equations for each drying application evaluated. R^2, SEE, RMSE and χ^2 values calculated for all drying methods were observed to be in the range of 0.8811-0.9997, 0.0069-0.1553, 0.00669-0.13891 and 0.00005-0.35714, respectively. Alibaş drying model was selected as the best model according to the highest R^2 and lowest SEE, RMSE and χ^2 values among Newton, Page, Henderson Pabis, logarithmic, diffusion, pony and logistic models in other drying methods, except for the drying study performed at 540W microwave power. The highest R^2 and lowest SEE, RMSE and χ^2 values were detected in the Alibaş model with solar tunnel type drying, 180W and 360W power, excluding 540W, and the lowest R^2 and highest χ^2 and RMSE values were determined in the Newton model at 540 W power. This means that the estimated data highly fit with the experimental data. In the literature, studies have been carried out by many researchers using single layer or thin layer drying models for different agricultural products (32, 33, 34, 35, and 36).

Table 2. Analysis inferences acquired from all model equations

			Microwave		
		Solar tunnel	**180W**	**360W**	**540W**
Newton	R^2	0.9598	0.8811	0.8753	0.8613
	SEE	0.0784	0.1275	0.1310	0.1438
	RMSE	0.0691	0.0847	0.1291	0.1389
	χ^2	0.0172	0.0322	0.1231	0.0751
Page	R^2	0.9621	0.9594	0.9661	0.9877
	SEE	0.0822	0.0751	0.0694	0.0444
	RMSE	0.0671	0.0325	0.0673	0.0413
	χ^2	0.0196	0.0240	0.3571	0.0650
Henderson and Pabis	R^2	0.9622	0.9055	0.8960	0.8997
	SEE	0.0821	0.1145	0.1215	0.1269
	RMSE	0.0670	0.0705	0.1179	0.1181
	χ^2	0.0171	0.0235	0.1209	0.0634
Logarithmic	R^2	0.9627	0.9949	0.9920	0.9966
	SEE	0.0894	0.0267	0.0342	0.0346
	RMSE	0.0666	0.0261	0.0327	0.0309
	χ^2	0.0158	0.0047	0.0002	0.0007
Diffusion	R^2	0.9598	0.8811	0.8753	0.8613
	SEE	0.0927	0.1293	0.1350	0.1553
	RMSE	0.0691	0.1267	0.1291	0.1389
	χ^2	0.0172	0.1953	0.1231	0.0751
Midilli et al.	R^2	0.9661	0.9994	0.9979	0.9291
	SEE	0.0952	0.0089	0.0180	0.1217
	RMSE	0.0634	0.0086	0.0169	0.0993
	χ^2	0.0157	0.0006	0.0000	0.0081
Alibas	R^2	0.9836	0,9997	0,9990	0,9992
	SEE	0.0765	0.0069	0.0175	0.0121
	RMSE	0.0441	0.0066	0.0161	0.0103
	χ^2	0.0147	0.0007	0.0009	0.0001
Logistic	R^2	0.9624	0.9611	0.9713	0.9860
	SEE	0.0897	0.0739	0.0648	0.0494
	RMSE	0.0668	0.0724	0.0619	0.0441
	χ^2	0.0179	1.2535	0.3334	0.0562

4. Discussion and Conclusion

The tunnel type solar dryer is primarily used for drying many fruits and vegetables in Isparta climate conditions. A constant rate period was not determined in the solar tunnel type and microwave drying with avocado samples. On the contrary, all trial methods were performed in the decreasing rate period. The moisture content of the avocado fruit which had an initial moisture content of 71.51%, was reduced to 14.23% w.b. The dehydration process in the solar tunnel dryer took about 3 days, whereas in the microwave dryer it was expressed in only minutes. It was found that the best model equation to explain the thin layer solar and microwave drying behavior of avocado fruit was the Alibaş model. Because when compared with the analysis results of other model equations, it was seen that the Alibaş model equation had the highest R^2, lowest SEE, RMSE and χ^2 values.

Declaration of Ethical Code

In this study, we undertake that all the rules required to be followed within the scope of the "Higher Education Institutions Scientific Research and Publication Ethics Directive" are complied with, and that none of the actions stated under the heading "Actions Against Scientific Research and Publication Ethics" are not carried out.

References

[1] Güzel, S. 2018. The effect of ultrasonic, ultraturrax and microwave pretreatment applied to oils obtained from different avacado species on oil yield and oil features. Erciyes University, Graduate School of Natural and Applied Sciences,109 p, Kayseri.

[2] Demircan, B., Velioğlu, Y. S. 2021. Avocado: Composition and Effects on Health. Academic Food Journal, 19(3), 309-324.

[3] Dreher, M. L., Davenport, A. J. 2013. Hass avocado composition and potential health effects. Critical Reviews in Food Science and Nutrition, 53, 738-750.

[4] Yahia, E. M., Woolf, A. B. 2011. Avocado (*Persea american* a Mill.). In Postharvest Biology and Technology of Tropical and Subtropical Fruits, Edited by E. Yahia, Woodhead Publishing, UK, 125-186.

[5] Saavedra, J., Córdova, A., Navarro, R., Díaz-Calderón, P., Fuentealba, C., Astudillo-Castro, C., Galvez, L. 2017. Industrial avocado waste: Functional compounds preservation by convective drying process. Journal of Food Engineering, 198, 81-90.

[6] Nguyen, T. K., Mondor, M. Ratti, C. 2018. Shrinkage of cellular food during air drying. Journal of Food Engineering, 230, 8-17.

[7] Alibas, I., Zia, M. P., Yilmaz, A., Asik, B. B. 2020. Drying kinetics and quality characteristics of green apple peel (*Mallus communis* L. var. "Granny Smith") used in herbal tea production. Journal of Food Processing and Preservation, 44(2), e14332.

[8] Mulato, S., Atmawinata, O., Yusianto, Handaka, Pass, T., Muehlbauer, W., Esper, A. 1999. Development of a solar cocoa processing center for cooperative use in Indonesia, The Planter, 75(875), 57-74.

[9] Lenaerts, S., Van Der Borght, M., Callens, A., Van Campenhout, L. 2018. Suitability of microwave drying for mealworms (*Tenebrio molitor*) as alternative to freze drying: impact on nutritional quality and colour. Food Chemistry, 254, 129-136.

[10] Naderinezhad S., Etesami N., Najafabady A. P. Falavarjani M. G. 2016. Mathematical modeling of drying of potato slices in a forced convective dryer based on important parameters. Food Science and Nutrition, 4(1): 110–118.

[11] Sacılık, K., Keskin, R., Elicin, A. K. 2006. Mathematical modelling of solar tunnel drying of thin layer organic tomato. Journal of Food Engineering, 73, 231-238.

[12] Schirmer, P., Janjai, S., Esper, A., Smitabhindu, R., Mühlbauer, W. 1996. Experimental investigation of the performance of the solar tunnel dryer for drying bananas. Renewable Energy, 7(2), 119-129.

[13] Eltawil, M. A., Azam, M. M., Alghannam, A. O. 2018. Energy analysis of hybrid solar tunnel dryer with PV system and solar collector for drying mint (*Mentha viridis*). Journal of Cleaner Production. 181, 352-364.

[14] Rathore, N. S., Panwar, N. L. 2010. Experimental studies on hemi cylindrical walk-in type solar tunnel dryer for grape drying. Applied Energy, 87(8), 2764-2767.

[15] Gürlek, G., Özbalta, N., Güngör, A. 2009. Solar tunnel drying characteristics and mathematical modelling of tomato. Journal of Thermal Science and Technology, 29(1), 15-23.

[16] Eliçin, A. K., Saçılık, K. 2005. An experimental study for solar tunnel drying of apple. The Journal of Agricultural Sciences, 11(2), 207-211.

[17] Tunckal C., Doymaz, İ. 2020. Performance analysis and mathematical modelling of banana slices in a heat pump drying system. Renewable Energy, 150, 918-923.

[18] Kipcak, A.S. 2017. Microwave drying kinetics of mussels mytilus edulis. Res. Chem. Intermed. 43:1429–1445. doi: 10.1007/s11164-016-2707-4.

[19] Kipcak, A. S., Doymaz, İ. 2020 Mathematical modeling and drying characteristics investigation of black mulberry dried by microwave method, International Journal of Fruit Science, 20(3), 1222-1233.

[20] Doymaz I., Kipcak A.S., Piskin S. 2015. Microwave drying of green bean slices: drying kinetics and physical quality. Czech J. Food Sci., 33, 367-376.

[21] Falade, K., Ogunwolu, O. S. 2014. Modeling of drying patterns of fresh and osmotically pretreated cooking banana and plantain slices. Journal of Food Processing and Preservation 38: 373–388.

[22] Westerman, P. W., White, G. M., Ross, I. J. (1973) Relative Humidity Effect on the High temperature drying of shelled corn. Transactions of the ASAE, 16, 1136-1139.

[23] Aghbashlo, M., Kianmehr, M. H., Khani, S., Ghasemi, M. 2011. Modelling the carrot thin-layer drying in a semiindustrial continuous band dryer. Czech Journal of Food Sciences, 29, 528–538.

[24] Chinenye, N. M., Ogunlowo, A. S., Olukunle, O. J. 2010. Cocoa bean (*Theobroma cacao* L.) drying kinetics. Chilean Journal of Agricultural Research, 70,633–639.

[25] Akpinar, A. K., Bicer, Y. 2008. Mathematical modeling of thin layer drying process of long green pepper in solar dryer and under open sun. Energy Conversion and Management, 49, 1367–1375.

[26] Yaldız, O., Ertekin, C. 2007. Thin-layer solar drying of some vegetables. Drying Technology, 19(3–4), 583–97.

[27] Midilli, A., Kucuk, H., Yapar, Z. 2002. A new model for single layer drying. Drying Technology, 20(7), 1503-1513.

[28] Alibas, I. 2012. Microwave drying of grapevine (*Vitis vinifera* L.) leaves and determination of some quality parameters. Journal of Agricultural Sciences, 18, 43-53.

[29] Alibas, I. 2012. Drying of thin layer mango slices with microwave technique. Anadolu J Agr Sci, 30, 99-109.

[30] Çelen İ. H., Çelen, S., Moralar, A., Buluş, H. N., Önler, E. 2015. Experımental Investigation of Potato Dryıng in Mıcrowave Belt Dryer. Electronic Journal of Vocational Colleges-Special Issue: The Latest Trends in Engineering, 5(4), 57–69.

[31] Demiray, E., Tulek, Y. 2017. The effect of pretreatments on air drying characteristics of persimmon. Heat and Mass Transfer, 53, 99-106.

[32] Akpınar E., Demirci, S. 2018. Mathematical models to determıne of thın layer dryıng kınetıc of gınger slıces. European Journal of Technique. 8(2), 110-123.

[33] Alibaş, İ. 2014. Mathematical modeling of microwave dried celery leaves and determination of the effective moisture diffusivities and activation energy. Food Sci. Technol, Campinas, 34(2), 394-401.

[34] Togrul, I. T., Pehlivan, D. 2004. Modelling of thin layer drying kinetics of some fruits under open-air sun drying process. Journal of Food Engineering, 65, 413-425.

[35] Alibaş, İ. 2012. Microwave drying of strawberry slices and the determination of the some quality parameters. Journal of Agricultural Machinery Science, 8(2), 161-170.

[36] Kucuk, H., A. Midilli, A. Kilic, and I. Dincer. 2014. A review on thin-layer drying-curve equations. Drying Technol, 32(7), 757–773.

[37] Doymaz, İ. 2009. Thın-layer dryıng of spınach leaves in a convectıve dryer. Journal of Food Process Engineering. 32(1), 112-125.