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Freeze-drying of persimmon (*diospyros kaki*) slices investigation of drying characteristics

*Dondurularak kurutulan trabzon hurması (*diospyros kaki*) dilimlerinin kurutma özelliklerinin incelenmesi*

Yazar(lar) (Author(s)): Abdullah DAĞDEVİREN¹, Bahadır ACAR², Abdullatif ALHAMMADIY³, Khandan ROŞHANAEL⁴, Tuba COŞKUN⁵, Özgür İNANÇ⁶ Mehmet ÖZKAYMAK⁷

ORCID¹ : 0000-0002-5418-4445

ORCID² : 0000-0002-9494-6301

ORCID³ : 0000-0002-7165-7435

ORCID⁴ : 0000-0002-1469-8812

ORCID⁵ : 0000-0003-2274-3481

ORCID⁶ : 0000-0001-6879-8555

ORCID⁷ : 0000-0002-4575-8988

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Freeze-Drying of Persimmon (*Diospyros Kaki*) Slices

Investigation of Drying Characteristics

Highlights

- ❖ Investigation of Freeze-Drying characteristic of Persimmon (*Diospyros Kaki*).
- ❖ The proper kinetic drying model was specified by using MATLAB software.
- ❖ The effective diffusivity (D_{eff}) values were computed by drawing drying value.

Graphical Abstract

The effective diffusivity (D_{eff}) values were computed by drawing experimental drying data in terms of $\ln(MR)$ was plotted versus time. The effective diffusivity coefficient must be ranged from 10^{-12} to 10^{-8} m^2/s for food products in literature and it is determined that the calculated effective diffusivity coefficients for Persimmon (*Diospyros Kaki*) products have good agreement with the literature.

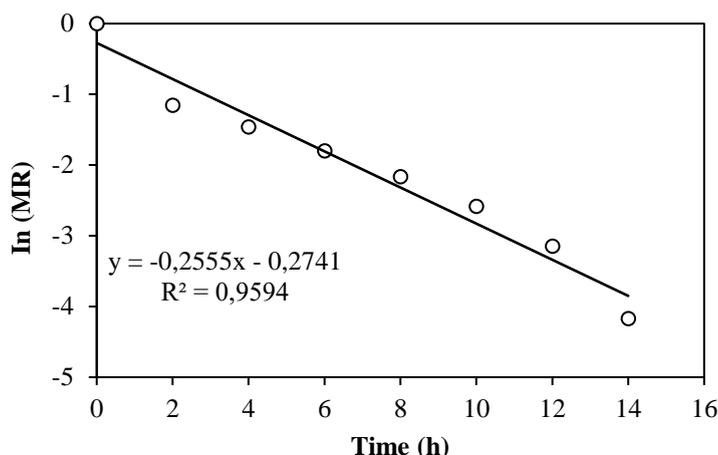


Figure. Plot of $\ln(MR)$ versus freeze-drying time for Persimmon samples

Aim

Aim of the present work was to identify the proper kinetic drying model by calculating MR and DR values for 8 different drying model with measuring mass losses in every two hours.

Design & Methodology

The Persimmon (*Diospyros Kaki*) fruit was sliced into thicknesses as 5 mm, and those sliced specimens were put in the freeze-drying device. Considering the experimental results, 8 different kinetic drying models were performed using MATLAB software.

Originality

Freeze-drying process of Persimmon (*Diospyros Kaki*) and investigation drying characteristic of process.

Findings

Results have shown that the effective diffusivity coefficients were within the limits that were presented in the literature as 10^{-12} – 10^{-8} m^2/s for food products. Among the 8 different kinetic drying models, the Page model was chosen as a proper kinetic drying model for Persimmon (*Diospyros Kaki*) products.

Conclusion

The proper kinetic drying model was specified by calculating MR and DR values for 8 different drying model with measuring mass losses in every two hours. The proper kinetic drying model was the Page model because the R^2 value was about 0,019483, X^2 value was about $5,062 \times 10^{-4}$, RMSE value was about 0,9558 respectively.

Declaration of Ethical Standards

The author(s) of this article declare that the materials and methods used in this study do not require ethical committee permission and/or legal-special permission.

Freeze-Drying of Persimmon (Diospyros Kaki) Slices Investigation of Drying Characteristics

Araştırma Makalesi / Research Article

Abdullah DAĞDEVİREN^{*1}, Bahadır ACAR², Abdullatif ALHAMMADIY², Khandan ROSHANAEE², Tuba COŞKUN², Özgür İNANÇ², Mehmet ÖZKAYMAK²

¹University of Karabuk, Iron and Steel Institute, Dynamic Laboratory, Karabuk, Turkey

²University of Karabuk, Faculty of Technology, Department of Energy Systems Engineering, Karabuk, Turkey

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ABSTRACT

This study was performed to define the kinetic drying model and to define the effective diffusivity coefficient of the fruit, which is called Diospyros kaki in the literature, from the family of Ebonaceae known as the Persimmon in our country. In the study, blueberries by the weight of 100 g and with a thickness of 5 mm were placed in the drying device, and the data were processed by observing the weight loss every two hours after being subjected to the drying process for 14 hours. 8 different kinetic drying models were applied to the acquired data using the Matlab program. As a result of the application, the estimated standard errors (RMSE), chi-square (X^2), regression coefficients (R^2) were calculated, error analysis was performed, R^2 , X^2 , and RMSE values were found, as 0.019483, 5.062×10^{-4} and 0.9558. According to these results, it was determined that the most suitable model is the Page model. Also, the effective diffusivity coefficients for Persimmon (Diospyros Kaki) were calculated as $1.79775 \times 10^{-10} \text{ m}^2/\text{s}$.

Keywords: Drying kinetics, drying of Persimmon (Diospyros Kaki), kinetic drying model, page model, effective diffusivity.

Dondurarak Kurutulan Trabzon Hurması (Diospyros Kaki) Dilimlerinin Kurutma Özelliklerinin İncelenmesi

ÖZ

Bu çalışma ülkemizde Cennet Hurması olarak bilinen Abanozgiller ailesinden literatürdeki adı Diospyros kaki olan meyvenin dondurarak kurutulması, kinetik kurutma modelinin belirlenmesi ve efektif difüzyon katsayısı belirlenmesi amacıyla yapılmıştır. Çalışmada 100 gr ve 5 mm et kalınlığına sahip yaban mersinleri kurutma cihazının içerisine yerleştirilmiş, 14 saat kurutma işlemine tabi tutularak her iki saatte bir ağırlık kayıpları gözlemlenerek veriler işlenmiştir. Elde edilen verilere Matlab programı kullanılarak 8 farklı kinetik kurutma modeli uygulanmıştır. Uygulama sonucunda tahmini standart hatalar olan (RMSE), ki-kare (X^2), regresyon katsayıları (R^2) hesaplanmış, hata analizleri yapılmış ve R^2 , X^2 , RMSE değerleri sırasıyla, 0,019483, $5,062 \times 10^{-4}$ ve 0,9558 olarak bulunmuştur. Bu sonuçlara göre en uygun modelin Page modeli olduğu belirlenmiştir. Ayrıca yaban mersini için efektif difüzyon katsayılarının $1,79775 \times 10^{-10} \text{ m}^2/\text{s}$ olarak hesaplanmıştır.

Anahtar Kelimeler : Kurutma kinetiği, Trabzon hurmasının kurutulması, kinetik kurutma modeli, page model, efektif difüzyon

1. INTRODUCTION

According to the literature, Persimmon (Diospyros kaki) is one of the most significant fruits grown commercially around the planetary, including East Asia (China, Japan, and other Far Eastern countries) and Mediterranean regions, and is grown for its nutritious fruits. [1]. Persimmon fruit is a significant supply of phenolic compounds, vitamin C, antioxidants, glucose, dietary fiber, and carotenoids, and it is used in the treatment of cardiovascular and digestive system diseases, as well as strengthening the immune system with its high tannin content, preventing diarrhea, appetite, stomach gastridine.

It has been reported to have positive effects in preventing, improving intestinal inflammation, eliminating anemia and vitamin deficiency. With him, complementary feeding practices are fundamental to the nutrition,

physical development, and survival of the baby in the first two years of life. On the other hand, hazelnut flour plays an important role in nutrition and health thank to its very specific nutritional value. Persimmon flour is a good source of protein and fat [2]. Paradise dates are consumed fresh and dried and can be used in various areas of the food industry (dessert, ice cream, marmalade, cream cake, molasses, puree, etc.). Since it plays an important role commercially, the production of paradise dates in the world has shown a significant increase in recent years and it is grown in 42 provinces in Turkey and the country's total annual production of paradise dates (in 2019 - Ordu

Commodity Exchange) has reached 51 thousand tons. determined [3]. Persimmon fruit's attractive orange color, sweet taste and texture have made this fruit a special area of interest for food scientists. Unripe, sweet, and non-biting fruits are nectars, gels, jams, etc. It can be used as a sweetening agent for fruit ice creams and bakery products, as well as material for products. In addition to

*Sorumlu Yazar (Corresponding Author)
e-posta : musaatar@gazi.edu.tr

fresh consumption, paradise dates are consumed by cutting them into salads, drying and freezing when they soften. The total amount of phenolic substance, which is the most important feature of the paradise date and gives a bitter taste, has decreased in marmalade compared to the raw material. As the fruit ratio was increased, the amount of total phenolic substance, carotene and lycopene increased accordingly [4]. The persimmon fruit, a single deciduous plant, can differ in color, shape, and size. Harvest time of the fruits starts from the end of September and continues until the beginning of December. Many of the varieties of paradise date have an astringent taste equal to when they are fully ripe. In autumn, just before the leaf falls, the leaves turn into 3 different colors, these colors are green, orange-red and red. In addition, these colors are used as ornamental plants as they contribute to romance as well as their relaxing feature that does not tire the eye. The color of the fruits turns from yellow to red or orange, its shape is round, and its taste is divided into 2 as it is bitter and not bitter [5]. Appearance is one of the most significant quality agents used in deciding the market value of the paradise dates as in other fruit types.

Quality: It is evaluated according to shape, size, color, the condition of the fruit and the amount of spoilage, especially the sugar content in the ripe fruit and the color change and the bitterness status are considered as the most important criteria in marketing [6]. Dehghani et al. assessed the impact of drying apple, which was osmotically pretreated using five concentrations of sucrose solution, four intermittent microwave power levels, convective hot air (40 °C) on drying kinetics, and four pulse ratios calculating energy consumption, effective moisture diffusion coefficient, bulk density, rehydration ratio, and shrinkage [7]. High hydrostatic pressure (HHP) is a possibility to pasteurization to conserve and stretch shelf life, in the study of M.Hern Gonzalez-Carrión et al. It has been shown that consumers perceive date palm whole and non-fat milk type (milkshake) as a high antioxidant drink. The "milkshake" containing HHP-treated dates scored the highest overall liking regardless of the type of milk and with untreated dates and wholly milk. Therefore, processing dates with HHP may make it thinkable to formulate palm milkshakes with high nutritional value and high acceptableness notwithstanding the season of the fruit [8]. In the study of Chang-Cheng Zhao et al, it was shown that the water loss of palm slices round hot air drying follows kinetic pattern and the increase in drying temperature drops significantly in most bioactive intricates. Taking into consideration the high cost and time consumption of the freeze drying technique as well as higher drying temperatures do not affect the drying rate after a certain drying period, it has been found that it is beneficial to control the temperature gradient round the hot air drying procedure [9]. In the study of Yingwei Qi et al. To examine melanin and its formation in the palm of paradise, it was observed that melanin accumulated in the cell walls and subepidermal cells of the upper

epidermis and the isolated pigment had lamellar structures. Fourier transform ultraviolet spectroscopy analysis revealed that the melanin in palm skin exhibits many characteristic absorption peaks and shows that the isolated pigment is a form of melanin [10]. Kırmacı et al.[11] freeze-dried 5mm and 7mm thick strawberries and tested their moisture ratio (MR) through finding the weight loss, after which, they applied a kinetic drying model that had appropriate RMSE and coefficient of resolution values. Although the study conducted by R.Martínez-Las Heras et al. on the attendance of antioxidant compounds and thence on the antioxidant mental ability of palm leaves and their extracts, it has shown that air drying at 100 °C will be the most suitable produce for stabilizing the palm leaves and then using them in brewed drinkables and similar. Thus, the well conditions for aqueous extraction to maximize the extractability of the antioxidant compounds corresponded to 90 °C for 60 minutes [12]. In the study of Ya-Ling Chang et al; The compositions and contents of antioxidant components and antioxidant properties were determined for the leaves of eight date harvested from September to November, and the compositions and contents of phenolic compounds and antioxidant qualification were also different for leaves from different date varieties. The leaves of date varieties of pollination constant and astringent (PCA) have higher phenolic content and better antioxidant effects [13]. In the study of Antonio Cutillas-Iturralde et al. Xyloglucan was extracted from the fruit cell walls of the Persimmon, purified, and chemically characterized from semi-celluloses extracted with alkali. Monosaccharide analysis of purified xyloglucan showed a Glc: Xyl: Gal: Fuc molar ratio of 10.0: 6.0: 3.4: 1.4, indicating a low degree of polymerization of the side chains [14]. Moraga et al.[8] conducted another study to explore mechanical and optical characteristics of two freeze-dried fruits, including apple and banana in sliced form. After calculating water content and water activity values, they reported significant varies, such as glass transition and water activity. Both the mentioned changes prevented varies in the mechanical properties of the samples. Their conclusion shows that only water activity is required for preventing against the browning reactions in fruits [15]. Freeze drying is a very clean drying method compared to other drying methods in terms of bacteria, dust and vitamins. It is recommended that people who are allergic to dust and pollen consume products that are dried with freeze-drying technology.

This study was carried out to determine the kinetic drying model and to define the effective diffusivity coefficient of the fruit, which is called Diospyros kaki in the literature.

2. MATERIAL AND METHOD

The sample of the paradise date used in our experimental study is shown in Figure 1. The weight of persimmon fruit is 100 g, its thickness is cut 5 mm and placed in the

test container and 7 pieces of this sample are prepared. After completing these preparations, it will be stabilized in the freezer and will be subjected to drying.

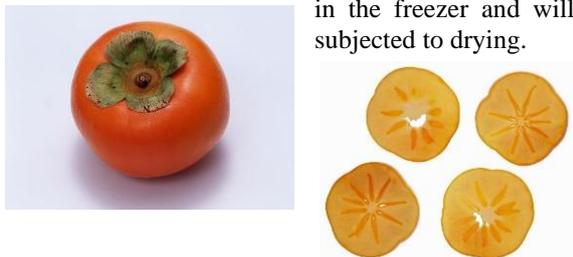


Figure 1. Persimmon (*Diospyros Kaki*) fruit

The freeze drying device used in our experimental studies is the ScanVac Coolsafe type device of the Labogene brand. Several options are available to configure freeze drying to suit your specific needs. In order to have a long life machine capacity, the condenser of the device is coated with Teflon, and it has easy cleaning opportunity to protect it from corrosion problems while working with aggressive acids. This device is suitable for freezing products that need very low evaporator temperatures (-55°C). The experiments were carried out by reducing the required pressure to a pressure of 0.01 kPa with the device connected to a vacuum pump with 1×10^{-4} mbar vacuum power. According to the conditions of our experiment, we reduced the pressure of 4×10^{-4} mbar of the vacuum pump with the vacuum power of the device to 0.01 kPa. The schematic view of the freeze drying device used for the experiment is shown in Figure 2.

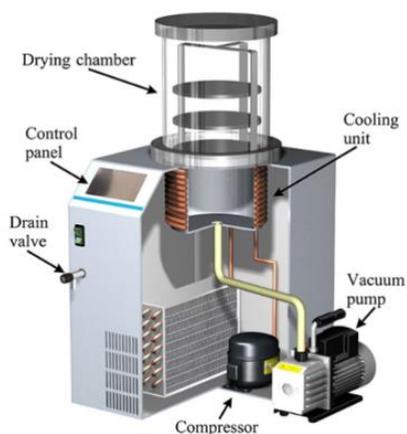


Figure 2. The freeze-drying device

The operating principle of the ScanVac Coolsafe device is focus on the freeze-drying operation of the frozen product at low pressure, by increasing the temperature of the frozen crop and the desired drying, resulting in the sublimation process (when solid substances are heated, they directly go into gas without transition to an intermediate liquid state). In our study, the vacuum pump function brings the pressure of the drying chamber to the desired pressure in order to obtain the desired physical properties (temperature, pressure), while the compressor of the device adjusts the temperature suitable for the in-

cabin drying processes. In order to keep the temperature and pressure in accordance with the conditions of our study, after the sample was placed in the drying room of the device, the temperature and pressure control panel was adjusted, and the device was operated, and our experiment was carried out. The logic of freeze drying is based on sublimation. When the product is frozen, it freezes in the moisture inside. If the test head is kept below the critical pressure value and the temperature increase is created, the moisture passes directly to the gas phase and is separated from the product moisture.

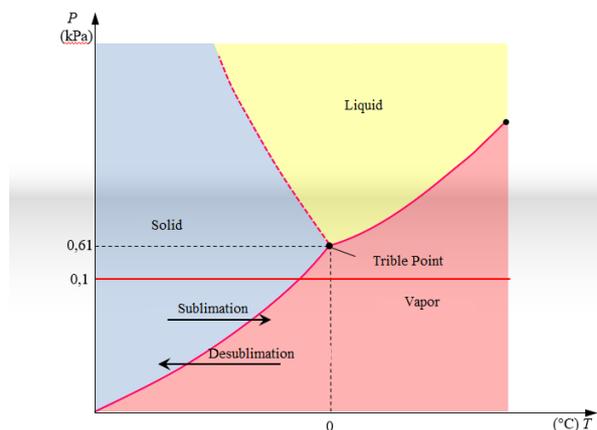


Figure 3. The basic logic freeze-drying

Before starting our experiment, the required temperature, pressure and working times (freeze drying time for date samples 14 hours) were made on the control panel. The time and temperature schedule has been prepared as shown in Figure 4. According to the

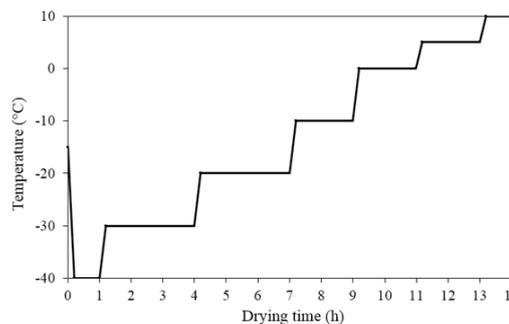


Figure 4. The temperature values as a function of drying time

planned working system, the slices of the heavenly dates taken out of the deep freezer at -15°C are placed in the device and stored for the first 60 minutes. Our experiment is started at -40°C and 0.01 kPa pressure, and then, keeping the pressure constant, 180 minutes at -30°C , 180 minutes at -20°C , 120 minutes at -10°C , and at 0°C . 120 min., 120 min. At 5°C . and finally at 10°C for 60 min. The process is carried out and when I complete these steps, the freeze-drying process is completed at the end of a total of 14 hours. In order to determine the weight loss of the sample during the experiment, 7 different samples were changed every two hours in the study. After taking the first sample to the device and running it to determine the weight loss, the weight loss of the date

sample is determined by using the precision balance (balance with sensitivity of 0.001 g) to confirm the weight loss at the end of two hours. After determining the weight loss of the first sample, the second sample is processed to the same drying settings and the device is operated and this time the process is continued for four hours instead of two hours, and the weight loss is measured after four hours. By performing the previous process for other date samples, the sample is taken to the device at the end of the 6th, 8th, 10th, 12th and last 14 hours and the loss of mass is determined. Then it is placed in the oven and approximately 60 minutes. kept waiting. Some food products contain a certain amount of moisture, such as persimmon. In order to mensurate the amount of moisture in the sample of the heavenly date used in our experimental study at the end of drying, the sample is operated into a desiccator. The sample is taken from the oven and placed in a desiccator designed of curved glass with plenty of silica gel and it is heated for about 15 minutes. it is kept waiting and then the rate of moisture is calculated by weighing it to the scale. It is possible to apply theoretical models for all kinds of matter and conditions, because when a model's solution is searched, it becomes difficult to use it because they have many parameters and complex structures connected to them. Despite the less complex nature of semi-theoretical models, the parameters contained in their equations are also limited in their usefulness to deal only with the products under consideration. There are no complex mathematical equations based on the data obtained in determining the drying rate of a product through experimental studies. However, the equations obtained in experimental studies are also valid for the sample and experiment conditions. The equation, which is the most widely used in semi-theoretical models, is known as the "logarithmic drying" equation [16].

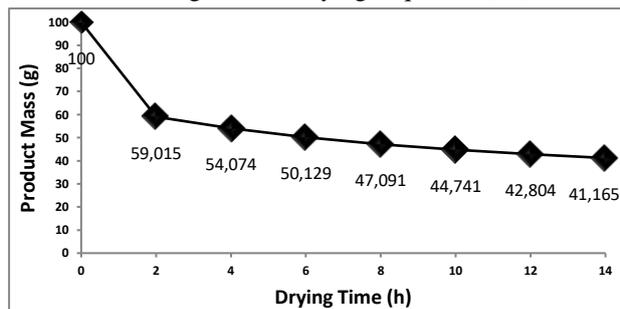


Figure 5. Mass loss of Persimmon (Diospyros Kaki) sample over time

Table 1. Empirical and semiempirical equations for drying kinetics

Model no	Model name	Model
1	Newton	$MR = \exp(-kt)$
2	Page	$MR = \exp(-kt^n)$
3	Modified Page I	$MR = \exp[-(kt)^n]$
4	Henderson ve Pabis	$MR = a \cdot \exp(-kt)$
5	Logarithmic	$MR = a \cdot \exp(-kt) + c$
6	Two-term eksponential	$MR = a \exp(-kt) + (1 - a) \exp(-kat)$
7	Wang and Singh	$MR = 1 + at + bt^2$
8	Diffusion approach	$MR = a \exp(-kt) + (1-a) \exp(-kbt)$

The moisture ratio (MR) is showing the changes of the Persimmon (Diospyros Kaki) sample as a function of time can be computed by equation (1). The drying rate (DR) can be computed using equation (2) as well.

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

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

The change of moisture rate (MR) over time (t), which is a dimensionless term, can be determined by the equation given in Equations 1 and 2. In the equation (M₀) the initial moisture content, (M_t) the moisture content at the, (M_d) is the equilibrium moisture content. The part on the left side of the equation gives the moisture ratio (MR) values which in non-dimensional and express the difference and alteration of the Persimmon (Diospyros Kaki) as a function of t moment of drying and could be computed so easily by the declared equation [19].

3. RESULT AND DISCUSSION

Figure 5 shows the experimental moisture ratio graph of the Persimmon (Diospyros Kaki) sample obtained because of freeze-drying for 14 hours.

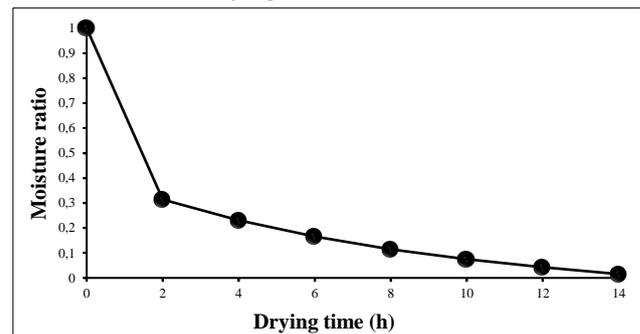


Figure 6. Moisture ratio of Persimmon (Diospyros Kaki)

The moisture content of the product is calculated experimentally and after determining the weight loss of this product depending on time, a graph is created based on mathematical models. It was ensured that the most suitable model was selected and determined from 8 different drying kinetic models applied in our freeze drying study. MATLAB program was used in the process of selecting the mathematical model

The RMSE, reduced X^2 of estimated values, and the coefficient adequacy of the decision (R^2) of kinetic models to prove the harmony and agreement between the moisture ratio of experimentally models and the predicted and guessed moisture and humidity values as statistical approach, can be found with the help of equations[17, 18].

$$RMSE = \left[\frac{1}{N} \sum_{i=1}^n (MR_{pre,i} - MR_{exp,i})^2 \right]^{1/2} \quad (4)$$

$$X^2 = \frac{\sum_{i=1}^n (MR_{exp} - MR_{pre})^2}{N - z} \quad (5)$$

$$R^2 = 1 - \left[\frac{\sum (MR_{exp} - MR_{pre})^2}{\sum (MR_{pre})^2} \right] \quad (6)$$

the most suitable model are determined by the multiple regression method. In the light of the data obtained, 8 models were applied, and the most suitable drying model was defined from these 8 different models. These determination criteria depend on the R^2 , X^2 , and RMSE values obtained from the models that shown in Table 2.

In table 2, R^2 , X^2 and RMSE values and results of 8 kinetic drying models given. As it can be easily seen here, the Page model due to the consideration of R^2 and X^2 amounts, the most suitable drying model with an R^2 value such as 9.558×10^{-1} , which is the closest value to 1, and the closest to zero by 5.062×10^{-4} as X^2 . Further another factor supporting the suitability of the Page model is that the root means square error (RMSE) value as the closest to 0, such as 1.9483×10^{-2} as a supporting

Table 2. The results calculated by 8 kinetic drying models.

Model No	Model Name	Model parameters	R^2	X^2	RMSE
1	Newton	k: 0.4134	0.9521	4.929×10^{-3}	0.065678
2	Page	k: 0.7569 n: 0.5262	0.9558	5.062×10^{-4}	0.019483
3	Modified Page I	k: 0.5799 n: 0.5317	0.9947	5.078×10^{-4}	0.019516
4	Henderson and Papis	a: 0.9635 k: 0.3967	0.9539	5.537×10^{-3}	0.064443
5	Logarithmic	a: 0.9138 c: 0.07533 k: 0.5599	0.9776	3.223×10^{-3}	0.044883
6	Two-term eksponential	a: 0.2782 k: 1.121	0.9731	3.235×10^{-3}	0.049261
7	Wang ve Sing	a: -0.2058 b: 0.01024	0.7932	2.483×10^{-2}	0.136482
8	Diffusion Approach	a: -1.545 b: 0.9977 k: 0.417	0.9521	6.902×10^{-3}	0.06568

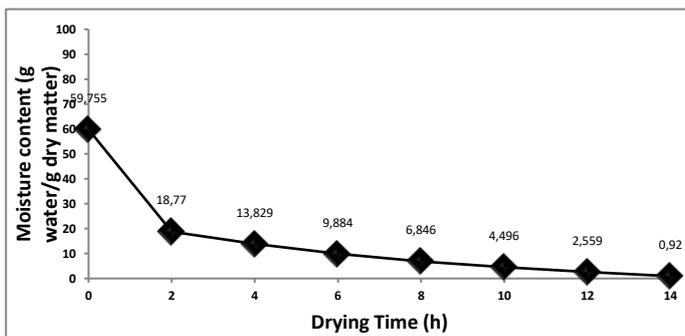


Figure 7. Moisture content of Persimmon (Diospyros Kaki) sample due to time

The estimated root means square error (RMSE) in Equation 3 indicates the divagation betwixt the estimated kinetic values and the experimental model. It is also stated in Equation 4 that the harmony increases with the reduced Chi-square (X^2) value. In addition to these, the modeling coefficient of determination (R^2) value in Equation 5 of the model explains the experimental data is an indicator of the usability of the model. According to the statistical evaluation results, the coefficients found in

factor for the Page model.

The comparison of the moisture rates acquired from the calculated page model with the moisture rates acquired from the experiments is shown in Figure 6. For food and material drying efficient diffusivity is an important transport characteristic that depends on the moisture content and temperature of a material. Fick's diffusion equation has a second law, which makes it a mass-diffusion equation for drying crop in a fall-rate phase. The moisture content of Persimmon decreasing over time is shown in figure 6.

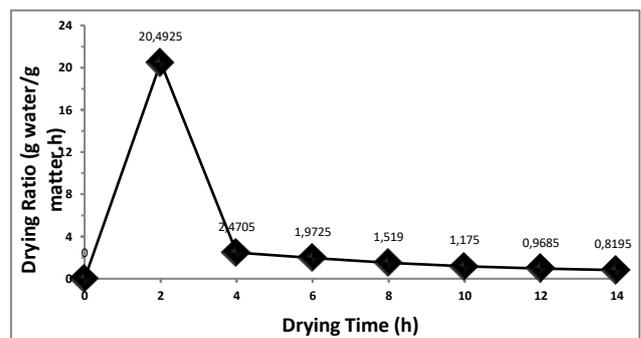


Figure 7. Drying ratio of Persimmon (Diospyros Kaki) sample due to time

The drying rate of the freeze-dried Persimmon slices is shown in Figure 8. At the early on the freeze-drying duration, the drying ratio exhibits incline behavior because of the high concentration of the moisture at the face of the product. To the end of the first 2 hours drying period, the drying rate decreased leisurely up to the end of the drying duration because of the increasing temperature of the plate in the freeze-drying device



Figure 8. Dry Persimmon (Diospyros Kaki)

According to Figure 7, it is seen that the drying rate diminished in parallel with diminishing of the moisture content. Afterward, the drying rate showed the rapid decline behavior within the initial 2 hours period because the temperature of the plate in the freeze-drying device was about -30 °C. The moisture content (MC) at the superficies of the product dried significantly. The freeze drying form of Persimmon slices is shown in Figure 8.

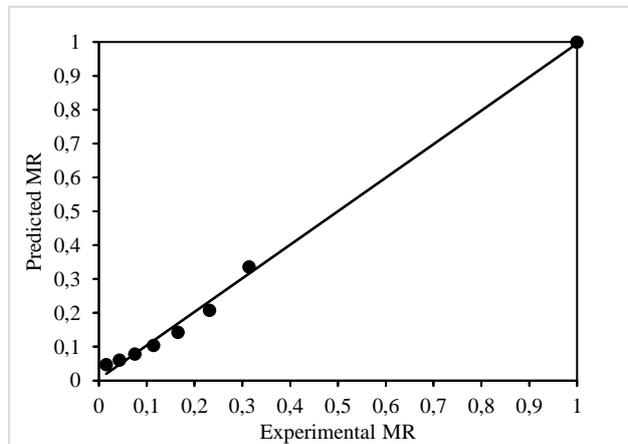


Figure 9. Comparing between experimental and estimated moisture ratio values applying the Page Model.

The drying processes’ theoretical model can be determined by its solution, which is shown in the equation given below:

$$\frac{\partial M}{\partial t} = D_{eff} \nabla^2 M \tag{6}$$

Diffusion equation solution (Eq. 6) for slice geometry was first used by Crank. He assumed that there is a negligible exterior resistance, uniform initial moisture distribution, negligible shrinkage, and constant diffusivity:[20]

$$MR = \frac{8}{\pi^2} \left[\exp\left(-\frac{\pi^2 D_{eff} t}{4L^2}\right) + \frac{1}{9} \exp\left(-9\frac{\pi^2 D_{eff} t}{4L^2}\right) + \frac{1}{25} \exp\left(-25\frac{\pi^2 D_{eff} t}{4L^2}\right) + \frac{1}{49} \exp\left(-49\frac{\pi^2 D_{eff} t}{4L^2}\right) \dots \right] \tag{7}$$

He assumed that there is a negligible exterior resistance, uniform initial moisture distribution, negligible shrinkage, and constant diffusivity:

$$MR = \frac{8}{\pi^2} \exp\left(-\frac{\pi^2 D_{eff} t}{4L^2}\right) \tag{8}$$

Here t defines drying time (s), Deff shows effective diffusivity, n presents a positive integer, and L shows half-thickness of the samples. Keeping in view long drying duration with steady diffusion coefficient in a Cartesian coordinate system, we simplified Equation 8 to a limiting form of the diffusion equation. After plotting the experimental drying data for ln(MR) versus time, we defined effective diffusivity (Deff) values Equation 7. After drawing the experimental drying values for ln(MR) versus time, we determined effective diffusivity (Deff) values, as Figure 10 shows.

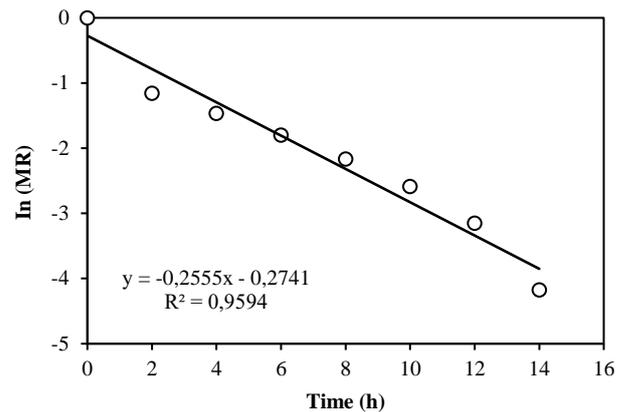


Figure 10. Plot of ln(MR) versus freeze-drying time for Persimmon (Diospyros Kaki) samples

Especially for the experimental study, uncertainty analysis is the common method to obtain a methodological approach about the precision and accuracy of the results [21]. The uncertainty analysis was conducted according to the Guide to the Expression of Uncertainty in Measurement [22], as seen in Equation X.

$$U_f = \sum_{n=1}^N \left(\frac{\partial f}{\partial x_n} u_n \right)^2 \tag{9}$$

Table 2. The uncertainty values

The freeze-drying device’s pressure	± 0,1
The freeze-drying device’s temperature	± 0,1
Precision balance	± 0,1
Oven	± 0

Formula 9 and table 2 are used for measurement uncertainty. In equation 9, overall uncertainty U_f for a value f (in our case founded drying characteristics) is calculated using Gaussian propagation of uncertainties where x_n are the independent variables, N is their number and u_n is uncertainty of associated variable x_n . When Equation X is transformed according to the uncertainty of associated values for drying characteristics, it calculated $\pm 0,1$. According to Equation 8 and Equation 10, a plot of $\ln(MR)$ versus drying time must give a straight line with a slope (K):

$$K = \frac{\pi^2 D_{eff}}{4L^2} \quad (10)$$

The effective diffusivity for the Persimmon slices with 5 mm thicknesses can be calculated by Equation 8. It was calculated about 2.25×10^{-10} m²/s for 5 mm thickness. The effective diffusivity coefficient must be ranged from 10^{-12} to 10^{-8} m²/s for food products in literature and it is determined that the calculated effective diffusivity coefficients for kiwi products have good agreement with the literature. In Figure 8, we found slope (K) from the Equation 8. For 5mm thick Persimmon slices, the effective diffusion value (D_{eff}) was determined using Equation 6, and its value was 2.57665×10^{-12} m²/s. From this research, the effective diffusion value was found within the reference range 10^{-12} – 10^{-8} m²/s for drying food materials. According to the literature, no research has been performed so far to establish Persimmon (Diospyros Kaki)’s kinetic model, and no attempt has been made to quantify its effective diffusivity or moisture content in the freeze-drying process [29]. We conclude that Persimmon (Diospyros Kaki)’s effective diffusivity has good agreement with the general effective diffusivity range for drying food materials [23].

4. CONCLUSION

In the study, a total of 7 Persimmon samples, each with a thickness of 5mm, set as 100 grams, were subjected to freeze-drying for 14 hours. MR (moisture ratio) was calculated with the weight loss data taken every two hours in different samples and the most suitable model was determined on 8 different drying models using the MATLAB program. As you seen in Figure 5 was determined that sliced Persimmon (Diospyros Kaki) had 60% moisture because of determination moisture content by stove and desiccator at the end of total 14 hours freeze-drying process. In addition to this, the proper kinetic drying model was specified by calculating MR and DR values for 8 different drying model with measuring mass losses in every two hours. In the calculation, it was seen that the most suitable model was the PAGE model with the R^2 value of $9,558 \times 10^{-1}$, the X^2 value of $5,062 \times 10^{-4}$, and the RMSE (root mean square root) value of $1,9483 \times 10^{-2}$. In the calculation, it was seen that the most suitable model was the PAGE model with the R^2 value of $9,558 \times 10^{-1}$, the X^2 value of $5,062 \times 10^{-4}$, and the RMSE (root mean square root) value of $1,9483 \times 10^{-2}$. It was

confirmed that the calculated effective diffusivity value was within the reference range mentioned in the literature (10^{-12} m²/s – 10^{-8} m²/s) for food products.

Nomenclature

a, b, c, n	The constants of the models
z	Number of parameters in the model
k, k₀, k₁	Drying rate constants (min ⁻¹)
t	Time (min)
M₀	The initial moisture content (g water/g dry matter)
M_t	The moisture content at a time t (g water/g dry matter)
M_a	The final equilibrium moisture content (g water/g dry matter)
MR	The moisture ratio (dimensionless)
N	Number of observations
MC	Moisture content (g water/g dry matter)
DR	Drying rate (g water/g dry matter.min)
D_{eff}	The effective diffusivity (m ² s ⁻¹)
L	Half-thickness of samples (m)
R²	Coefficient of determination
χ²	Reduced chi-square
RMSE	Root mean square error

DECLARATION OF ETHICAL STANDARDS

The authors of this article declare that the materials and methods used in this study do not require ethical committee permission and/or legal-special permission.

AUTHORS’ CONTRIBUTIONS

Abdullah DAĞDEVİREN: Performed the experiments and analyze the results.

Bahadır ACAR: Performed the experiments and analyze the results.

Abdullatif ALHAMMADIY: Performed the experiments and analyze the results.

Khandan ROSHANAËİ: Wrote the manuscript.

Tuba ÇOŞKUN: Wrote the manuscript.

Özgür İNANÇ: Wrote the manuscript.

Mehmet ÖZKAYMAK: Wrote the manuscript.

CONFLICT OF INTEREST

There is no conflict of interest in this study.

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