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Experimental investigation of freeze-dried kanlıca mushroom (lactarius salmonicolor)

Dondurularak kurutulan kanlıca mantarının (lactarius salmonicolor) deneysel olarak incelenmesi.

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Experimental Investigation of Freeze-Dried of Kanlıca Mushroom (Lactarius Salmonicolor)

Highlights

- *Investigation of Freeze-Drying characteristics of Kanlıca Mushroom (Lactarius Salmonicolor).*
- *The proper kinetic drying model was specified by using MATLAB software.*
- *The effective diffusivity (D_{eff}) values were computed by drawing the 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 Kanlıca Mushroom (Lactarius Salmonicolor) products have good agreement with the literature.

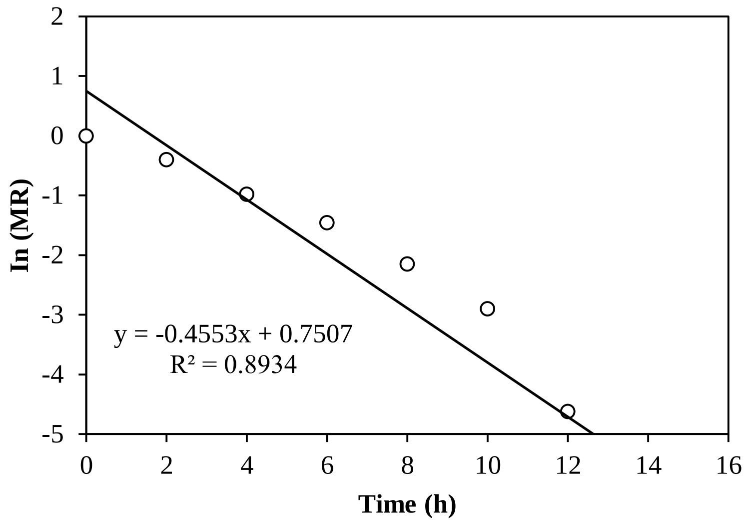

Figure. The plot of In (MR) versus freeze-drying time for *Kanlıca Mushroom*

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

Kanlıca Mushroom (Lactarius Salmonicolor) 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 Kanlıca Mushroom (Lactarius Salmonicolor) 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 Kanlıca Mushroom (Lactarius Salmonicolor) 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 0,9988, X^2 value was about 1,851 x 10^{-4}, RMSE value was about 0,01358 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.

Experimental Investigation of Freeze-Dried of Kanlıca Mushroom (Lactarius Salmoncolor)

Araştırma Makalesi / Research Article

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ABSTRACT

In this study, it is examined to prevent the formation of toxins by providing drying of the kanlıca mushroom, which is unique to Karabük, by freezing, to extend the shelf life, to take measures against early decay and spoilage. As the dried product, kanlıca mushroom, which is an endemic plant, contains high amounts of protein and amino acids. In this study, the 5 mm thick cut kanlıca mushroom was placed in a freeze-drying device and the drying process was initiated. Weight losses during drying were recorded and kinetic models were created. In the experiment lasting 14 hours in total, 100 gr. The weights of the canlica mushrooms were measured every two hours and MR (Moisture rates) were calculated. According to our results, the lowest chi-square (X^2) was 1.851 x10^{-4} and the estimated standard error (RMSE) value was 0.01358. The correlation value (R^2) was calculated as 0.9988, close to one. The best Page model gave these results from the kinetic models. The effective diffusivity for the Kanlıca Mushroom with 5 mm thicknesses can be calculated at about 3.2035×10^{-10} m^2/s. It was confirmed that the calculated effective diffusivity value was within the reference range mentioned in the literature (10^{-12} m^2/s – 10^{-8} m^2/s) for food products.

Keywords: **Drying kinetics, drying of kanlıca mushroom (lactarius salmoncolor), kinetic drying model, page model, effective diffusivity.**

Dondurarak Kurutulan Kanlıca Mantarının (Lactarius Salmonicolor) Deneysel Olarak İncelenmesi

ÖZ

Yaptığımız bu çalışmada, Karabük'e özgü olan kanlıca mantarının dondurarak kurutulması sağlanarak afla toksin oluşumuna engel olunması, raf ömrü uzatımı, erken çürüme ve bozulmaya karşı önlem alınması hedeflenmektedir. Kurutulan ürün olarak, endemik bir bitki olan yüksek miktarda protein ve amino asit içeren kanlıca mantarı kullanılmıştır. Literatürde, konu ile alakalı direkt çalışma bulunmamaktadır. Bu çalışmada 5 mm kalınlığında kesilen kanlıca mantarı dondurarak kurutma cihazına konularak kurutma işlemi başlatılmıştır. Kurutma sırasında ağırlık kayıpları belirlenip kinetik modelleri oluşturulmuştur. Toplam süre 14 saat olarak belirlenen deneyde 100 gr. kanlıca mantarının her iki saatte bir ağırlıkları ölçülüp MR (Nem oranları) hesaplanmıştır. Bulduğumuz sonuçlara göre en düşük khi-kare (X^2) 1,851 x10^{-4} ve tahmini standart hata (RMSE) değeri 0,01358 olarak bulunmuştur. Korelasyon değeri (R^2) ise bire yakın olacak şekilde 0,9988 olarak hesaplanmıştır. Kinetik modellerden bu sonuçları en iyi Page modeli vermiştir. 5 mm kalınlıktaki Kanlıca Mantarı için efektif yayılma gücü yaklaşık 3.2035×10^{-10} m^2/s olarak hesaplanmıştır. Hesaplanan efektif yayılım değerinin, gıda ürünleri için literatürde belirtilen (10^{-12} m^2/s – 10^{-8} m^2/s) referans aralığında olduğu doğrulanmıştır.

Anahtar Kelimeler: **Kurutma kinetiği, kanlıca mantarının kurutulması, kinetik kurutma modeli, page model, efektif difüzivite.**

1. INTRODUCTION

Foods are known as the most important source of nutrients for people to sustain their lives. In the case of food production on increasing demand, there is a need for storage. As a result of this storage, factors such as long-term storage without deterioration, preservation of aroma and nutritional values create the need for storage techniques. Various methods are used to store food. The most widely used of these methods is the drying process. The drying process is the removal of water from the product. It is explained as the process of removing water or other volatile substances from solid materials. In our country, many foodstuffs are traditionally dried by laying in the sun. This process takes place for a long time and causes microbiological deterioration and unwanted bacteria are formed in the product. In such a case, foods can be dried with alternative methods, The freeze-drying method is one of them and the freeze-drying method was applied in this study [1]. In freeze-drying application, the foodstuff is frozen first. A high degree of vacuum associated with a

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low-temperature condenser or chemical dehumidifier is taken into the applied volume. Heat transfer to the frozen food is provided by infrared radiation or conduction.

Meanwhile, the water in the ice phase in the food is removed by sublimation (evaporation) and the drying process is carried out. Freeze-drying technology is mostly used in instant coffee production. The food technology that best preserves the aroma in coffee is known as freeze-drying. In addition, the freeze-drying method is used in many different areas such as serums, products used in pharmacy, bacterial cultures, pharmaceutical industry, fruit, fruit juices, vegetable, and tea extracts [2]. Freeze-dried products are considered to have the same properties as fresh ones. It ensures that the properties of fresh samples such as appearance, taste, nutrients, color, flavor, texture, and biological activity are preserved and preserved. This technique can be applied to the drying of nutrients and is made one of the most effective processes. Freeze drying is called Lyophilization. It is carried out at temperatures and pressures below the triple point to ensure the sublimation of ice. Therefore, this method is the most suitable method for drying heat-labile compounds [3]. Akpınar and Bicer examined the drying behavior of apple slices in a convective type of cyclone dryer and studied mathematical modeling using the monolayer drying models in the literature. They compared 11 different monolayer drying models to define the drying behavior of apples. As a result, they determined that the logarithmic model for apple samples was the best model indicating the drying property. Mathematical models showing monolayer drying curves were analyzed by non-linear regression analysis. Considering the parameters such as drying time, moisture transfer, speed, and temperature of the drying air, apple slices dried in conditions higher than the optimum processing conditions[4]. Kırmacı conducted the design, manufacture and performance tests of the freeze drying system in his study. Strawberries sliced in 5 and 7 mm thickness were dried in the manufactured system. Error analyzes of the results of the models were performed using researched standard error (RMSE), chi-square (X^2) and regression coefficient (R^2). According to the results obtained, it was determined that the Page model was the closest to the experimental results [2]. Liapis developed a model that includes both desorption of water and sublimation of ice in the dried zone. This model is called the sorption-sublimation model [5]. Khalloufi et al. experimentally freeze-drying strawberries, blueberries, and mushrooms for 72 hours. As a result of the experiment, the relative humidity was increased from 11% to 87% with saturated salt solutions. The weight changes and water activity of the fruits during the drying process were studied and they stated that the GAB model was suitable as a result of the experimental data [6]. Acar et al. compared freeze-drying and sun-drying of saffron flower. Weight losses of freeze-dried saffron flowers were calculated during a total drying period of 16 hours. When the results were examined, it was seen that the saffron ratio of freeze-dried Saffron was 5 times higher than that of sun-dried samples. According to the experimental results obtained, the Page model was found to be closer than other models [7]. In the study of Kırmacı et al., freeze-drying of strawberries cut in 5 mm and 7 mm thickness and their weight loss during drying were calculated (MR) and moisture ratios were calculated. In the study, Page determined the most suitable kinetic drying model according to the estimated standard error (RMSE) and correlation values [8]. In the study we have done, the product to be freeze-dried is an endemic plant, the Kanlıca mushroom. Due to its climatic conditions and vegetation, our country is very rich in natural mushrooms that grow in different environments [9]. Lactarius sp, which is popularly known as Kanlıca, has many species in the study area. The most common and important of these are Lactarius deliciosus and Lactarius salmonicolor. These species are seen in the autumn season after the rain and until the snowfalls. It is located under conifers. This fungus, which can grow in acidic and calcareous soils, prefers humus soils of the Pinaceae family. Its general appearance is in the form of a convex hat consisting of orange-yellowish rings. They are easily distinguished from other fungi. This is because when they are plucked, they secrete orange-colored milk. That's why it got its name from the Latin word "Lac", which means milk because of its secretion. The color of the milk is a very important characteristic for the identification of Lactarius species. It is commonly found in forest ecosystems of Kastamonu, Karabük, Sinop, Balıkesir, İzmir and Bursa. It is also found in many European countries. It is the most common edible mushroom species collected from nature and sold in markets [10]. Öztürk used Agaricus bisporus, Lentinus edodes, Pleurotus ostreatus and Lactarius delicious mushroom species as material in his study. He dried the mushrooms by freeze drying, infrared and oven drying methods. In dried mushroom samples; The changes in various nutrients such as color, total phenolic substance content, rehydration capacity, antioxidant activity were investigated. When the antioxidant activity and total phenolic content of fresh and dried mushrooms were examined, it was determined that Agaricus bisporus, Pleurotus ostreatus, Lentinus edodes and Lactirus deliciosus species were in order from the highest to the lowest [11]. In this study, we tried to determine the most suitable kinetic drying model of freeze-dried Kanlıca mushroom with the weight losses we obtained by freeze-drying the Kanlıca mushroom. 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 paper was focus on determine the kinetic drying model and to define the effective diffusivity coefficient of the fruit, which is called Kanlıca mushroom in the literature.

2. MATERIAL AND METHOD

The sample of the Kanlıca mushroom used in this experimental study is shown in Figure 1. The weight of Kanlıca mushroom 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. Kanlıca Mushroom (Lactarius Salmonicolor)

The Kanlıca mushroom that we used in our experimental study was sliced in the form of 100 gr and 5 mm thick and placed on baking trays. 7 Kanlıca mushroom samples, which were sliced and prepared the day before, were kept in the deep freezer. Experimental studies were started the next day. Scanvac Coolsafe type freeze-drying device of Labogene brand was used in our study. Experimental studies were carried out by diminishing the pressure to the required 0.01 kPa with the device connected to the vacuum pump with a vacuum power of $4x10^{-4}$ mbar. With the evaporator temperature falling to -55 °C, the freezing process of the products can take place inside the device. The device we used for the freeze-drying is shown in Figure 2.

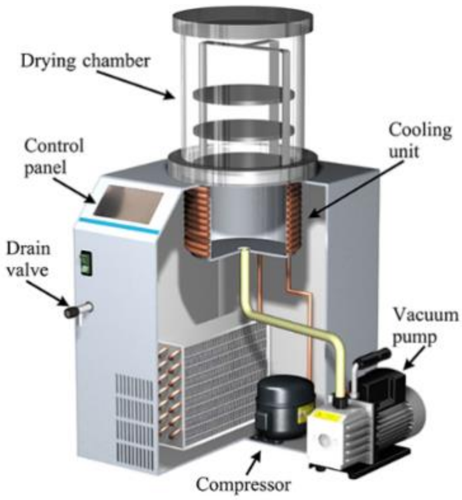

Figure 2. The device of freeze-drying

The operating principle of the ScanVac Coolsafe device is to 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 enclosure 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.

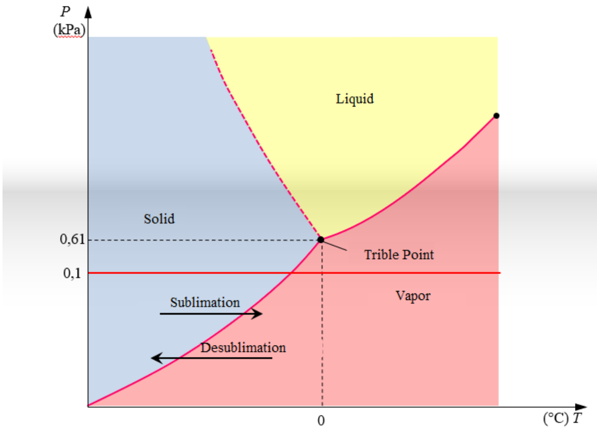

Figure 3. The logic of freeze-drying

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

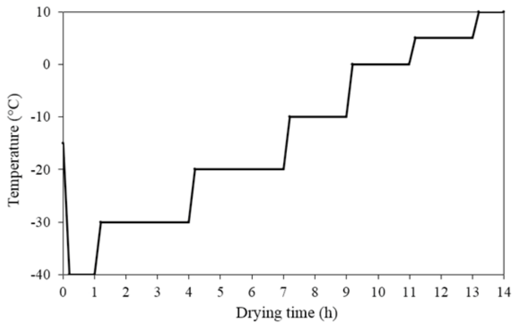

Figure 4. The temperature values as a function of drying time

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 120 minutes at 0 °C, at 5 °C and finally at 10 °C for 60 minutes. 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. To determine the weight loss of the Kanlıca Mushroom 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 data sample is determined by using the precision balance (balance with a 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 the mass is determined. In Figure 5, the mass loss of the Kanlıca mushroom sample according to the drying time is shown. 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. 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.

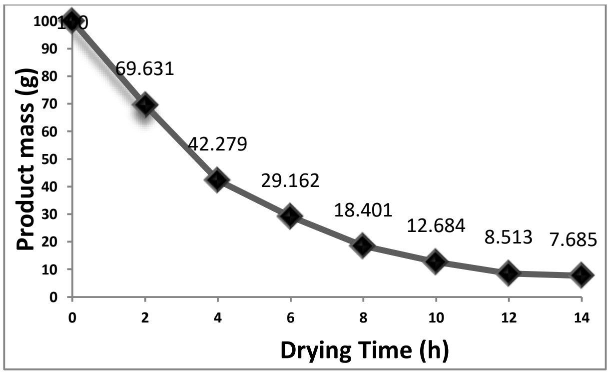

Figure 5. Mass loss of Kanlıca Mushroom sample over time

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. After all, 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]. 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.

$$MR = \frac{M_{\mathrm{t}} - M_{\mathrm{d}}}{M_0 - M_{\mathrm{d}}} \quad (1)$$

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

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 (M_0) 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 DİSCUSSİON

Figure 6 shows the experimental moisture ratio graph of the Kanlıca Mushroom sample obtained because of freeze-drying for 14 hours.

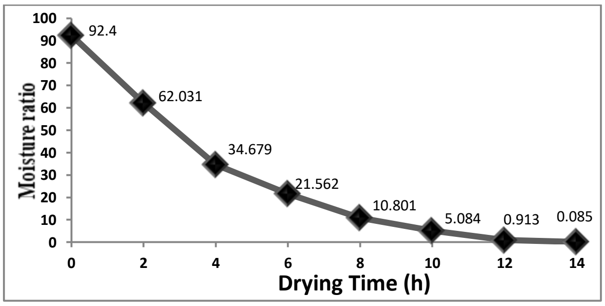

Table 1. Empirical and semiempirical equations for drying kinetics

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	$MR = a.\exp(-kt)$
5	Logarithmic	$MR = a.\exp(-kt) + c$
6	Two-term eksponential	$MR = aexp(-kt) + (1-a)\exp(-kat)$
7	Wang and Singh	$MR = 1 + at + bt^2$
8	Diffusion approach	MR = aexp(-kt)+(1-a)exp(-kbt)

Figure 6. A moisture ratio of Kanlıca Mushroom sample over time

After calculating the moisture content of the samples and obtaining the time-dependent weight losses, the graph was created according to the mathematical models. In this way, the most suitable one of the 8 different drying kinetic models applied was determined. A MATLAB program was used to determine these models. In Table 1, 8 different drying kinetic model formulas showing the estimated humidity ratios (MR) used in the MATLAB program are given.

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 a statistical approach, can be found with the help of equations[17, 18].

$$RMSE = \left[\frac{-1}{N}\sum_{i=1}^{N}\left(MR_{tahmini} - MR_{deneysel}\right)^2\right]^{½} \quad (3)$$

$$X^2 = \frac{\sum_{i=1}^{n}\left(MR_{exp} - MR_{pre}\right)^2}{N-z} \quad (4)$$

$$R^2 = 1 - \left[\frac{\sum\left(MR_{exp} - MR_{pre}\right)^2}{\sum\left(MR_{pre}\right)^2}\right] \quad (5)$$

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 defined the experimental data is an indicator of the usability of the model. According to the statistical results, the coefficients found in the most suitable model are determined by the multiple regression method. According to 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 shown in Table 2.

In table 2, R^2, $X^{2,}$ and RMSE values and results of 8 kinetic drying models are given. As it can be easily seen here, the Page model due to the consideration of R^2 and X^2 amounts is the most suitable drying model with an R^2 value such as 9.988×10^{-1}, which is the closest value to 1, and the closest to zero by 1.851×10^{-4} as X^2. The suitability of the Page model is that the root means square error (RMSE) value is the closest to 0, such as 1.358×10^{-2} as a supporting factor for the Page model.

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

Model No	Model Name	Model parameters	R^2	X^2	RMSE
1	Newton	k: 0.2471	0.9914	1.115×10^{-3}	0.0334
2	**Page**	**k: 0.1726** **n: 1,222**	**0.9988**	$\mathbf{1.851 \times 10^{-4}}$	**0.01358**
3	Modified Page I	k: 0.2371 n: 1.233	0.9987	1.865×10^{-4}	0.01366
4	Henderson and Papis	a: 1.027 k: 0.2528	0.9923	1.116×10^{-3}	0.0341
5	Logarithmic	a: 1.083 c: -0.07075 k: 0.212	0.9978	3.982×10^{-4}	0.01996
6	Two-term eksponential	a: 1.774 k: 0.3378	0.9986	2.137×10^{-4}	0.01462
7	Wang ve Sing	a: -0.171 b: 0.007273	0.9926	1.076×10^{-3}	0.02381
8	Diffusion Approach	a: 3.895 b: 0.8494 k: 0.1515	0.9982	3.321×10^{-4}	0.01823

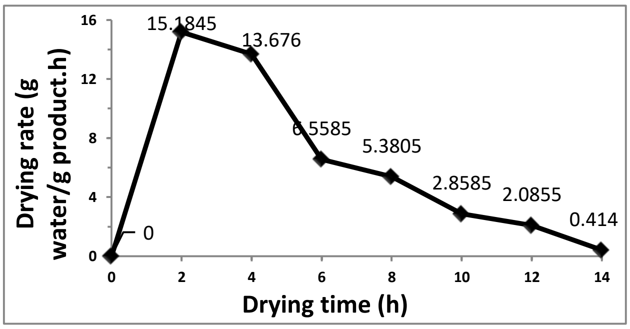

Figure 7. The drying rate of Kanlıca Mushroom sample over time

The drying rate of the freeze-dried Kanlıca Mushroom is shown in Figure 7. At the early freeze-drying duration, the drying ratio exhibits incline behavior because of the high concentration of moisture at the face of the product. At the end of the first 2 hours of the 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 Kanlıca Mushroom (Lactarius Salmonicolor)

According to Figure 6, it is seen that the drying rate diminished in parallel with the diminishing of the moisture content. Afterward, the drying rate showed a 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 Kanlıca Mushroom is shown in Figure 8.

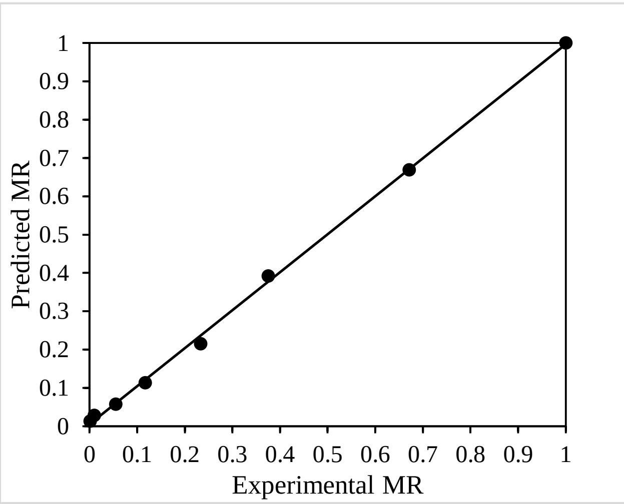

Figure 9. Comparing experimental and estimated moisture ratio values applying the Page Model.

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

$$\frac{\partial \mathrm{M}}{\partial t} = D_{\mathrm{eff}} \nabla^2 \mathrm{M} \quad (6)$$

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]

$$MR = \frac{8}{\pi^2}\begin{bmatrix} exp\left(-\frac{\pi^2 D_{eff}\, t}{4L^2}\right) + \frac{1}{9} exp\left(-9\frac{\pi^2 D_{eff}\, t}{4L^2}\right) \\ + \frac{1}{25} exp\left(-25\frac{\pi^2 D_{eff}\, t}{4L^2}\right) + \frac{1}{49} exp\left(-49\frac{\pi^2 D_{eff}\, t}{4L^2}\right) \ldots . \end{bmatrix} \quad (7)$$

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

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

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 7 to a limiting form of the diffusion equation. After plotting the experimental drying data for ln (MR) versus time, we defined effective diffusivity (D_{eff}) values Equation 6. After drawing the experimental drying values for ln (MR) versus time, we determined effective diffusivity (D_{eff}) values, as Figure 9 shows. The ln (MR) values of the Kanlıca mushroom samples according to the freeze-drying time are shown in the graph in Figure 10.

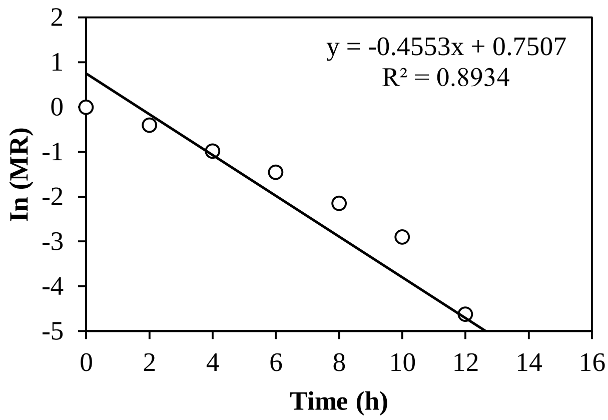

Figure 10. The plot of In (MR) versus freeze-drying time for Kanlıca Mushroom samples

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.

$$U_f = \sum_{n=1}^{N}\left(\frac{\partial_f}{\partial_{x_n}} u_n\right)^2 \quad (X)$$

In equation X, the 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 the uncertainty of the associated variable x_n. When Equation X is transformed according to the uncertainty of associated values for drying characteristics, it is calculated ± 0,1. According to Equation 7 and Equation 8, a plot of ln (MR) versus drying time must give a straight line with a slope (K):

$$\mathrm{K} = \frac{\pi^2 D_{\mathrm{eff}}}{4L^2} \qquad (9)$$

The effective diffusivity for the Kanlıca Mushroom with 5 mm thicknesses can be calculated by Equation 8. It was calculated about 3.2035×10^{-10} m^2/s for 5 mm thickness. 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 Kanlıca Mushroom products have good agreement with the literature. In Figure 8, we found slope (K) from Equation 9. For 5mm thick Kanlıca Mushroom, the effective diffusion value (D_{eff}) was determined using Equation 6, and its value was 2.57665×10^{-12} m^2/s. From this research, the effective diffusion value was found within the reference range 10^{-12}–10^{-8} m^2/s for drying food materials. According to the literature, no research has been performed so far to establish Kanlıca Mushroom 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 Kanlıca Mushroom'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 Kanlıca Mushroom 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 have seen in Figure 5 was determined that sliced Kanlıca Mushroom had 92% 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 models with measuring mass losses every two hours. In the calculation, it was seen that the most suitable model was the PAGE model with the R^2 value of 9,988×10^{-1}, the X^2 value of 1,851×10^{-4}, and the RMSE (root mean square root) value of 1,358×10^{-2}. The effective diffusivity for the Kanlıca Mushroom with 5 mm thicknesses can be calculated at about 3.2035×10^{-10} m^2/s. It was confirmed that the calculated effective diffusivity value was within the reference range mentioned in the literature (10^{-12} m^2/s – 10^{-8} m^2/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)
M_0	The initial moisture content (g water/g dry matter)
M_t	The moisture content at a time t (g water/g dry matter)
M_d	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)
D_{eff}	The effective diffusivity (m^2s^{-1})
L	Half-thickness of samples (m)
R^2	Coefficient of determination
χ^2	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

Göknur KAYATAŞ ONGUN: Performed the experiments and analyze the results.

Mehmet ÖZKAYMAK: Analyze the results.

Bahadır ACAR: Performed the experiments and analyze the results.

Mustafa AKTAŞ: Analyze the results.

Abdullah DADEVİREN: Wrote the manuscript.

CONFLICT OF INTEREST

There is no conflict of interest in this study.

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