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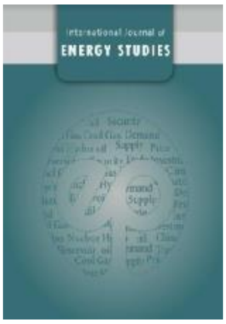

Research Article

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Freeze- drying of carrot slices in diverse thicknesses

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Highlights

- This paper concerns the importance of healthy foods due to the methods of drying.
- Investigation of Freeze-Drying characteristic of carrot slices with various thicknesses.
- The proper kinetic drying model was specified by using MATLAB software.
- A blended approach proposed to categorize the best drying method and heat transfer in this study.
- The detail of the drying, especially vegetable drying has analyzed.

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ABSTRACT

In this paper we dried carrots by the method of freeze-drying. The carrots had cut into slices; then divided in halves. The mass looses of samples sized. The mass losses measured and recorded during the process. The sections were in 5 mm and 7 mm. Slices were dried with SCANVAC COOLSAFE. The masses of the carrot slices differed also in each unit with the same mass and shape varied. Our team did the drying procedures every two hours, also the experiment was applied at different temperatures. While evaluating the number of carrot slices as samples for freeze-dried observed that, dried samples amount were 5 times less than the number of carrots before drying. The procedure was applied to 10 different mathematical models using the MATLAB program. The error analysis of the models at the result made by using the root-mean-square error (RMSE), chi-square (X^2) and regression coefficients (R^2). According to the results, it was sdetermined that the results of the Page model were closer as the experimental results be compared to other models. The statistical error values of samples for R^2, RMSE respectively were 0.018565707 for 5 mm and 0.019532936 for 7 mm.

Keywords: *Freeze drying, vegetable drying, kinetic drying mode*

1. INTRODUCTION

A carrot has a tentacle root plant. Owe the advantage of the spreading roots in the soil. The variant coloring of Dichroic and also several colors like purple, reddish-purple, yellow, and semi-white. Changing of carrot color to red is the indicator of an increase in the amount of carotene content in that vegetable. As it is obvious, the human body needs from 1 to 5 mg of carotene per day. Nowadays carrots are available all-round the year, as they are grown in vast climate situations like hot summer under plastic roofing to protect the plant from the harsh heat of the sun [1,3]. All growing time of the carrots from seed to harvest time will last up to four months (120 days) to be matured. But most cultivars mature within 70 to 80 days under normal conditions [4]. Moderate situations to have better yield and quality characteristics of carrots will vary from 10 to 15°C [4]. Many methods are used for drying, and one of these methods is the freeze-drying process. This process is a kind of process that takes place as follows: First, the food that is aimed to freeze with the drying process by reducing its internal moisture and leads to become less prone to spoilage. In this stage, the snow phase is converted into a steam or vapor phase by evaporation during an almost vacuum-free environment. Finally, after all these processes the moisture of foods will decrease so much. The entire dewatering (dehydration) process takes place in a lower temperature environment. As a comparison with traditional dryer moisture drainage in this method is better than the above-mentioned methods. The advantages of the freeze-drying system are to preserve most of the food's property to a greater extent. Many subsistence needs to be protected and preserved in several ways to expand their shelf lives. On the other hand, carrot as a vegetable has less shelf life because of its construction that leads to deteriorating quickly within time. The drying process has become a genuine vegetable preservation method to keep foods and boost the shelf life of nourishment. Though word of time here plays a great role in enlarging the life of vegetables [5]. Better quality recoverability, after water absorption and added value, are important issues in food preservation methods. In this study, we will be benefiting from carrots as the sample. Food Vacuum freeze dryers methods mostly have been used for drying the meat, vegetables, and spices, as well as in aquatic products, instant foods. On the other hand, we can admit that this method is used for general, also important and expensive food or medical products [6]. According to the sharp growth ratio of population, which results in increasing the market demand's drastic growth, the value of the method being more emphasized to everybody. Because the quality of the Freeze-drying products is compatible with the present with the green environment and these products are comfortable and healthy. They are now destinations and alternatives to old, unhealthy, unfriendly environment methods, which harm the societies in the past. As mentioned above, this process reduces the internal moisture of foods, vegetables and by applying, maintaining the correct system of drying on them. The freeze-drying technique is reducing the surrounding pressure of the item, which leads to allowing the frozen water in the material to sublimate directly from the solid phase to the gaseous phase, consequently achieving the purpose of the drying process. One of the major merit or bonus of this system is the products after trying the freeze-drying method can keep at normal temperature and there is no need to keep freeze-drying products in a cool environment. As they can be kept a long time at the normal temperature, which means the same with fresh materials after soaking, so it is very popular with both all types with different wealth customers. Also, as everybody knows there are many food drying techniques and storage methods to extend food life and protect goods. One of the traditional and so famous methods of preservation of foodstuffs is drying. Drying can be defined as the process of removing the water in a product consisting mainly of water and dry matter by various methods. The methods applied for drying vegetables and fruits are based on the principle of evaporating the water contained in the product to be dried by applying heat and mass transfer simultaneously. In technical drying, external intervention is made to the drying process and the moisture, which contained in the item, is removed by different methods. For this reason, drying is defined as separating the moisture of the product from products and as an outcome to be dried in the desired dryness values. The whole process applied to the product (heating, dehumidification, dehumidification, etc.) that enables the item to reach drying values in a certain period is called the "drying system". The drying process is widely applied in many branches of industry (such as food, paper, cement, timber, and moreover chemical industry). Drying applied to foodstuffs has many purposes, and perhaps the most obvious of them or most emphasized of them is to prevent the product to be spoiled during long-term storage. At the end of the drying process, the product can be stored for a long time without decay or ruining, by reducing the moisture of the product to a sufficient level to limit and cease microbial growth or other biological reactions. In addition, by reducing the moisture content of the product, quality features such as aroma and nutritional value are preserved. At the same time, decreasing the product volume at the end of the drying process causes to improve efficiency in transport and storage of foodstuffs. Using a dryer can assist to dry carrots. Drying by techniques such as Freeze- drying helps to keep and retain the bright orange color and the flavor of the carrots, reduce their size, and store them in small spaces. We cut the carrots into 7 mm and 5 slices, the quantity, size are 100 g mass, also using a device SCANVAC COOLSAFE, up to a temperature of -40 °C, for a period of up to 14 hours. Nowadays, carrots are one of the vegetables, which are used as a vital and essential component for human nutrition because they contain a high percentage of fiber and vitamins. Besides carrots are one of the important sources of beta-carotenoids that prevent cancer. Carrots have a giant source of vitamin A and potassium, further contain cholesterol-lowering pectin, vitamin B, vitamin C, folic acid, thiamine, and magnesium. Dried carrots are also used in dried soups and powder form in sauces and pastries. The purpose of drying carrots is to be stored safely over a long period. However, the volume and mass will be greatly reduced, and the costs of packaging, storage, and transportation will be diminished. There are many traditional drying process and each of them has its strong point and weak point. In our research and case study, we selected the ideal method, which is freezing, drying, because of its various virtues and values. As we mentioned above the used product was carrot and the reason that why carrot has been selected as the case study is the value and importance of this vegetable for all human beings also animal life.

2. MATERIALS AND METHOD

The carrots that were used in our experimental study, are shown in Figure 1. As it can be seen each particle mass is 100 g. They were cut into 5 mm and 7 mm thick slices and placed in containers. There were 7 samples of carrots, each slice prepared, were put in the deep freezer for one day before, and the experiments were started from the next day after keeping in the deep freezer.

Figure 1. Carrots samples prepared in 5 mm and 7 mm thickness.

The freeze-drying device used in our studies is the Scanvac Coolsafe kind of the Labogene brand. As the evaporator temperature decline to -40 °C, then the freezing process of the products officially performed inside the Scanvac Coolsafe device. The device is connected and linked to a vacuum pump with a vacuum power of 4×10^{-4} mbar. The experiments were carried out by reducing the pressure, which needed to become the pressure for 1×10^{-2} kPa. The schematic view of the freeze-drying device used in the experiment is shown in Figure 2.

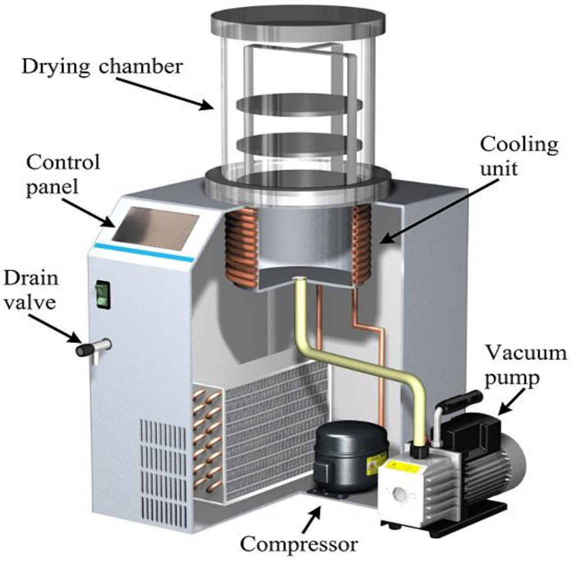


Figure 2. The freeze-drying device.

The working principle of the freeze-drying deviceis shown in Figure.2. The technique is based on the sublimation process of the frozen product by increasing its temperature at low pressure. Here, the vacuum pump reduces the desired pressure in the drying chamber, while the compressor adjusts the temperature inside the cabin. In this investigation we have the place, the product in the drying room of the device and then the device had started to act by adjusting temperature and pressure by setting them from the control panel. Before starting the device action, necessary adjustments should be done by entering the right amounts and adjusting the appropriate pressure, temperature and working time on the monitoring panels, which is the brain part of the device. Freeze-drying time for samples was set to 14 hours. The time and temperature schedule be arranged and in Figure 3 their relation has been revealed. Convention to the planned system, carrot slices taken out from the freezer at -15 °C temperature, then placed in the device, therefore stored there for the first 60 minutes. The first stage for freeze-drying procedure was adjusted to -40 °C temperature and 1×10^{-2} kPa pressure. Secondly, p slices kept on constant pressure for 180 minutes time and -30 °C as temperature. Other steps were180 minutes at -20 °C, 120 minutes at -10 °C, 120 minutes at 0 °C, 120 min at 5 °C, and final products kept in at 10 °C for 60 min. After all these sequence treatment, with same drying parameters, the freeze-drying process was performed at the end of a total of 14 hours.

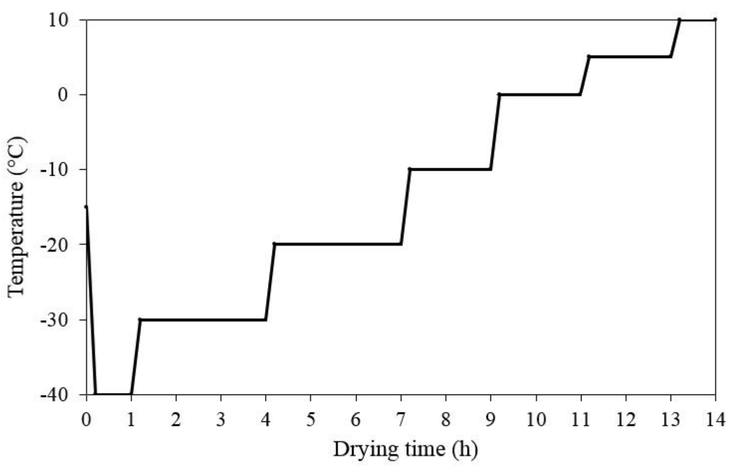


Figure 3. Temperature and time graph.

The reason for preparing 7 different samples for the study was to be able the measuring mass loss every two hours. For this reason, after placing the first sample in the device, the device had turned on. The sample after 2 hours removed and mass loss was measured by using a precision scale with 1×10^{-3} g resolution. The second sample was positioned into the device and the device operated by dependent on the same drying adjustment also same drying parameters. The sample was taken from the device at the end of the 4th hour and on this account the mass loss at the end of the 4th hour calculated too. This sequence drying process was applied to the rest of the carrots samples and the specimen pointed at the end of the 6., 8., and 10. 12. And last 14 hours and then placed in the oven for about 60 minutes. After the sample was taken from the oven and placed in a desiccator that was made have curved glass with plenty of silica gel in. Afterward, the dried carrots took out from the desiccator and their mass was measured. As mentioned before, using precious scale the measuring done. Our researcher did the measuring as they were intended to check, control and calculate the removing moisture of the vegetable and being sure that the freeze-drying process has been done completely. After taking out the carrots from the drying oven, put them into the desiccator for a quarter of an hour or 15 minutes. However after desiccator sprocedure the carrots were measured with a precision scale and the results were noted and recorded. The goal of this process was to remove the moisture content of the vegetable completely and also was a double check trigger for control of the freeze–drying process. Though this way is an accurate measuring of the liquid and wateriness of the dried products, which can be gained. Theoretical and empirical models can be examined on many kinds of items and materials and conditions. However, solving these equations required many factors which include various complex structures that reduce the usefulness of such models. On top of that semi-theoretical patterns do not have many complex structures, the usage of mentioned above patterns had restricted as the factors in equations only depend on to the relevant product. There are no complex mathematical equations in determining the drying ratio based on the data obtained by experimental means. However, the equations only valid on the sample and experiment conditions. The equation, which is the most and widely used in semi-theoretical models, has known as the "logarithmic drying" equation [1]. The moisture ratio (MR) that is a non-dimensional term and shows the changes of the carrot as a function of time can be calculated by equation (1). The drying ratio (DR) can be calculated using equation (2) as well.

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

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

In the equation 1, (M_0) refers to the initial moisture, (M_t) to write about the moisture at time, (M_d) introduce the equilibrium moisture. The part on the left side of the equation gives the moisture ratio (MR) values at different times of drying. The drying ratio Mt (DR) given in Equation 2 is in the amount of moisture at the time, while M_{t+dt} is t+dt exposes the amount of moisture at time[2] .

3. RESULTS AND DISCUSSION

Figure 4 displays the experimental moisture ratio graph obtained after 14 hours of freeze-drying of 5 mm and 7 mm thickly sliced carrots patterns.

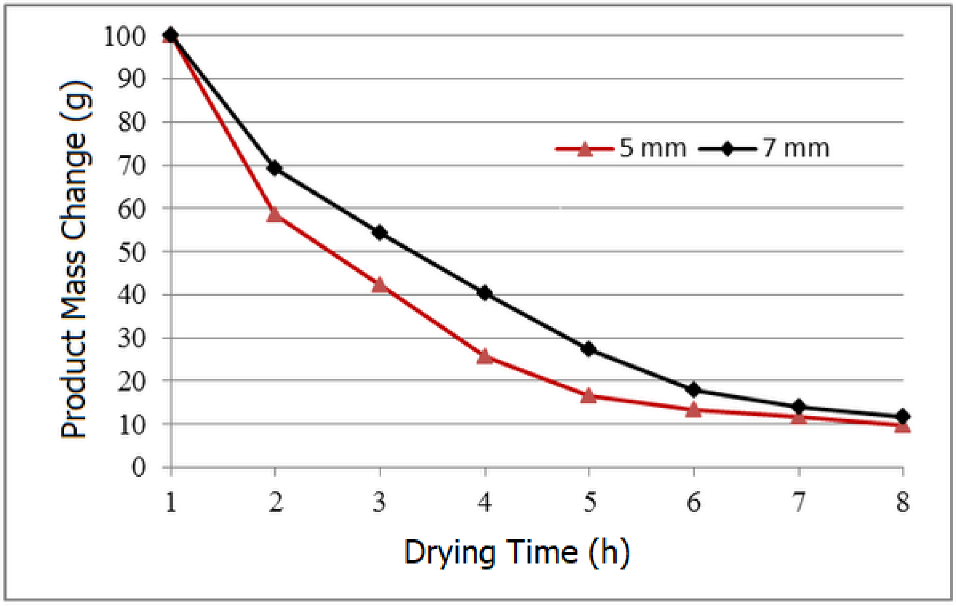


Figure 4. Moisture ratio of samples according to time.

After molding the moisture content of the products and recording the mass loss or mass loss due to time, a graph based on mathematical models was drawn and the most appropriate one was determined from 8 different drying kinetic models. A MATLAB program was used to perform these operations. In Table 1, a total of 8 different drying kinetic models reveals the estimated moisture content (MR), which has been used in the MATLAB program [3] .

Table 1. Empirical and semi-empirical equations for drying kinetics [4].

Model no	Model name	Model
1	Newton [7]	$MR = \exp(-kt)$
2	Page [8]	$MR = \exp(-kt^n)$
3	Modified Page I [9]	$MR = \exp[-(kt)^n]$
4	Henderson ve Pabis [10]	$MR = a.\exp(-kt)$
5	Logarithmic [11]	$MR = a.\exp(-kt) + c$
6	Two-term eksponential [12]	$MR = a.\exp(-kt) + (1-a)\exp(-kat)$
7	Wang and Singh [13]	$MR = 1 + at + bt^2$
8	Diffusionapproach [14]	$MR = a\exp(-kt) + (1-a)\exp(-kbt)$

Root-mean-square error (RMSE), chi-square (X^2) values, and the modeling adequacy of the model (R^2) to statistically explain the harmony between the experimentally found models and the predicted moisture values. It can be found by the assistance of equations given in [15,16].

$$RMSE = [\frac{1}{N}\sum_{i=1}^{n}(MR_{pre,i} - MR_{\exp,i})^2]^{1/2} \quad (3)$$

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

Root-mean-square error (RMSE) displayed in Equation 3 presents the deviation between the estimated values obtained with the model and the experimental values. It also stated in Equation 4 that the harmony increases with the decrease ratio in the chi-square (X^2) value. In addition, the modeling adequacy (R^2) value in Equation 5 of the model explains the experimental data is an indicator of the usability of the model. In compliance with the statistical evaluation results, the coefficients in the most suitable model were determined by the multiple regression method.

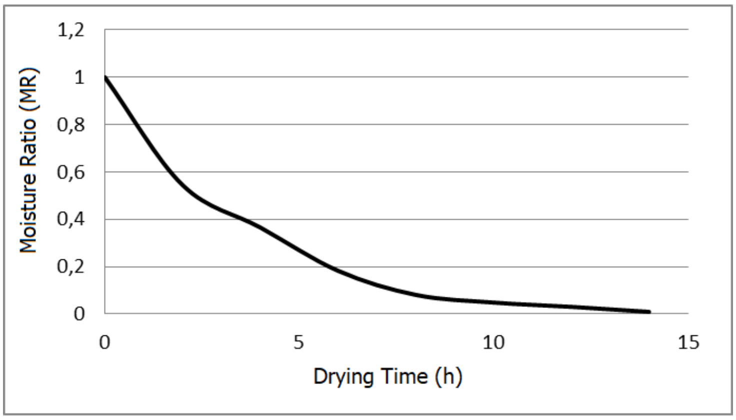
In the light of the data obtained, 8 models were applied and the most suitable drying model was determined from these 8 different models. These determination criteria depend on the R^2, X^2 and RMSE that has been obtained from the models.

Table 2. Results obtained from models used for drying kinetics.

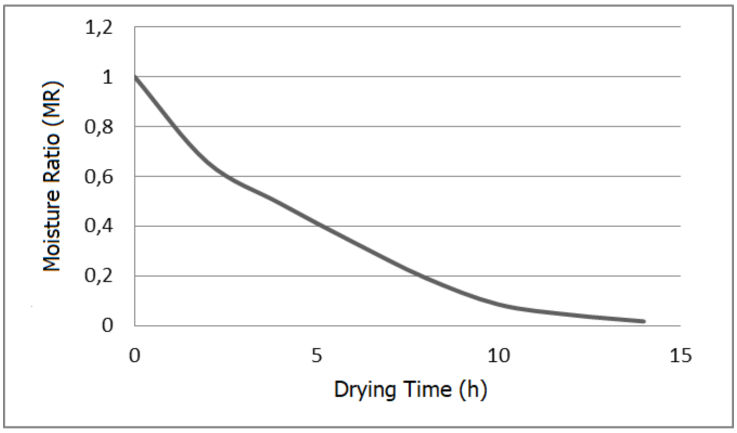
Model No	sample	Model parameters	R^2	X^2	RMSE
1	5	k = 0,2834	0.9956	0.00048221	0.01989184
	7	k = 0,203	0.9885	0.00137433	0.034677683
2	5	k = 0,2782 n = 1,012	0.9962	0.00052435	0.019830898
	7	k = 0,1597 n = 1,133	0.9906	0.00111842	0.028962264
3	5	k = 0,3006 n = 0,9776	0.9982	0.00074693	0.023668484
	7	k = 0,1917 n = 1,286	0.9861	0.00166132	0.035298552
4	5	a = 0,9978 k = 0,2828	0.9962	0.00052666	0.019874495
	7	a = 1,011 k = 0,2052	0.9868	0.00157694	0.034390515
5	5	a = 1,01 c = -0,01652 k = 0,2696	0.9987	0.0004515	0.018565707
	7	a = 1,108 c = -0,1885 k = 0,1573	0.9949	0.00061046	0.019532936
6	5	a = 1,339 k = 0,3093	0.9963	0.0005089	0.019536411
	7	a = 0,001989	0.9865	0.00161294	0.034780848

		k = 101,9			
7	5	a = -0,1861 b = 0,008529	0.9726	0.00380867	0.053446242
	7	a = -0,1476 b = 0,005604	0.9918	0.00098255	0.027146104
8	5	a = 0,03202 b = 0,05582 k = 4,931	0.9962	0.00062677	0.019792268
	7	a = 6,564 b = 1,083 k = 0,2962	0.9897	0.00122402	0.027658831

Table 2 exposes R^2, X^2 and RMSE values that given by 8 models. Here, for both 5 mm and 7 mm carrots, the Logarithmic model was observed as the most proper drying model with an R^2 value such as 0.9897, which is adjacent to 1, and the closest to 0, 0.00062677 and 0.00122402 as X^2 values, respectively. Another factor supporting the suitability of the Logarithmic model is that the root means square error (RMSE) value is close to 0, such as 0.019792268 and 0.027658831. This ratio, which was high at first, demonstrates a rapid decrease in the first two hours and shows a slower decline after that.



Figures 5. Moisture amount according to the drying time of carrots samples 5 mm.



Figures 6. Moisture amount according to the drying time of carrots samples 7 mm.

After the first 2 hours, the drying ratio decreases gradually until the end of the drying process as a result of the increase in the plate temperature of the freeze dryer. Figure 5 clearly shows that the drying ratio decreases with decreasing moisture content. Due to the high amount of moisture contained in the 7 mm thick carrots as the sample, the drying speed is slower in the first two hours. The 5 mm thick carrots sample achieved faster drying due to its low moisture content. The water vapor formed on the surface as a result of sublimation is created by transferring the freeze-dried sample to the dried area with the help of a capillary channel to the sample surface [17, 18]. The condenser of the freeze-dryer removes water vapor that reaches the surface of the sample because the partial water vapor pressure at the surface of the condenser is significantly lower than the partial water vapor pressure at the surface of the freeze-dried sample [19]. The theoretical model, which has found extensive research opportunities in the thin layer drying process of various foods, is determined by the solution of Fick's second law [2].

$$\frac{\partial M}{\partial t} = D_{eff} \nabla^2 M \tag{5}$$

In Equation 5, when the diffusion coefficient is fixed and solved for Cartesian coordinates and simplified with appropriate boundary conditions, Equation 6 is found.

$$MR = \frac{8}{\pi^2} \exp\left(-\frac{\pi^2 D_{eff} t}{4L^2}\right) \tag{6}$$

Where Deff is the effective diffusivity (m^2/s), it is the drying time (s), L is the half-thickness of the samples m and n is a positive integer [2] .

4. CONCLUSION

In this study, the freeze-drying process was carried out in the carrots slices, which, prepared in 5 mm and 7 mm thicknesses. Each of the masses of the slice was 100 g. As a result of the determination of the moisture content with an oven and desiccator at the end of the 14-hour freeze-drying process, it was determined that the 100 g 7 mm thick carrot slice contains 69.178 g moisture, and the 5 mm thick carrots slice has 58.554 g moisture. In addition, the most suitable drying model was determined on 8 different drying models by calculating MR and DR with the mass loss data taken every two hours. The R^2 value was 0.9962 and 0.9897 for X^2 values were determined as 0.00062677 and 0.00122402 for 5 mm and 7 mm, respectively. The root mean square error (RMSE) values were 0.019792268 and 0.027658831, that it was seen that the most suitable model was the Logarithmic model. Later, in the samples whose moisture content and drying speed were examined, it was observed that the drying ratio was slow due to the high amount of moisture contained in the 7 mm thick carrots sample, but a faster drying occurrs in the 5 mm thick carrots sample due to the low moisture content. Effective diffusion coefficient values calculated based on In (MR) was found to be 0.008949 m^2/s for 5 mm and 0.017877 m^2/s for 7 mm.

NOMENCALTURE

a, b, c,	The constants of the models
z	Number of parameters in model
k, k_0, k_1	Drying ratio 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 ratio (g water/g dry matter)
Deff	The effective diffusivity (m^2/s)
L	Half-thickness of samples (m)
R^2	Coefficient of determination
X^2	Reduced chi-square
RMSE	Root mean square error

Declaration of Ethical Standards

The authors of the paper submitted declare/declares that nothing which is necessary for achieving the paper requires ethical committee and/or legal-special permissions.

Contribution of the Authors

Bahadır Acar: Conceptualization, Methodology.

Abdullah Dağdeviren: Methodology, Writing - Original Draft, Writing - Review & Editing.

Ahmed Janaani: Conceptualization.

Khandan Roshanaei: Writing - Original Draft, Writing - Review & Editing.

Edip Taşkesen: Conceptualization, Investigation.

Göknur K. Ongun: Data Curation.

Mehmet Özkaymak: Supervision.

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