Şeyma UYSAL, Funda TURAN, Erinç KOÇAK, Gülden OVA, Fikret PAZIR

Ege University Engineering Faculty Food Engineering Department, Bornova, İzmir

Inspection of the drying kinetics for spaghetti squash *(Cucurbita Pepo L.)*

Summary

The aim of this work was to examine the drying kinetics of spaghetti squash (Cucurbita pepo L.) under the different temperature and air velocities with tray dryer. Drying process was carried out by placing the samples into the tray dryer at temperatures of 40; 50; 60 and 70 °C and air velocities of 1; 1.4 and 1.8 m/s with an initial thickness of the samples 0.6±0.2 mm. Examination of drying kinetics of spaghetti squash was carried out by testing the conformance of Newton Page Henderson, Modified Page, and Pabis Logarithmic Two – term exponential Two – term, Diffusion approach Modified Henderson and Pabis, Verma and Midilli which were widely used in food drying. Nonlinear regression was used for calculating the goodness of fit and model coefficients. Goodness of fit was determined according to the comparison of the regression coefficient, sum of squares error and reduced chi-square. As a result of the statistical analysis, it was found that Midilli was the best model which describes the drying kinetics. Effective diffusion coefficient (D_{eff}) was varying from $4.15 \cdot 10^{-10}$ to $2.04 \cdot 10^{-9}$ m²/s with respect to the drying temperatures. The relationship between drying temperature and effective diffusion coefficients was confirmed by the Arrhenius theory for all air velocities.

Keywords: *Cucurbita pepo L, moisture ratio, drying kinetics, thin layer drying*

Wyznaczanie kinetyki suszenia dla dyni makaronowej *(Cucurbita Pepo L.)*

Streszczenie

Celem pracy było wyznaczenie kinetyki suszenia dyni makaronowej (Cucurbita pepo L.) dla różnych temperatur i prędkości powietrza. Proces suszenia przeprowadzono przy temperaturach 40, 50, 60 i 70°C i prędkościach powietrza 1, 1,4 i 1,8 m/s. Próbki o grubości 0,6 ± 0,2 mm umieszczano na tacach suszarniczych. Do opisu kinetyki suszenia dyniowego spaghetti zastosowano matematyczne modele Newtona, Page, Modified Page, Hendersona i Pabisa, Logarithmic, Two term, Exponential Two term, Diffusion Approach, Modified Henderson i Pabis, Verma i Midilli, które są powszechnie używane w suszeniu żywności. Współczynniki dopasowania i współczynniki modelu określono na podstawie regresji nieliniowej. Poprawność dopasowania określono w oparciu o porównanie współczynnika regresji, sumy błędów kwadratów i zredukowanego chi-kwadrat. W wyniku analizy statystycznej stwierdzono, że Midilli był najlepszym modelem opisującym kinetykę suszenia. Współczynnik skuteczności dyfuzji (D_{eff}) mieścił się w przedziale od $4,15 \cdot 10^{-10}$ do $2,04 \cdot 10^{-9}$ m²/s w odniesieniu do temperatur suszenia. Zależność pomiędzy temperaturą suszenia a współczynnikiem dyfuzji została potwierdzony teorią Arrheniusa dla wszystkich przyjętych w planie badań prędkości powietrza.

Słowa kluczowe: *Cucurbita pepo L, wilgotność, krzywa suszenia, suszenie cienkowarstwowe*

Nomenclature

a - Semi empirical model Difusion approach constant;	D_{eff} - Effective moisture diffusivity;
b - Semi empirical model Difusion approach constant;	E_a - Activation energy [kJ/mol];
c - Semi empirical model Difusion approach constant;	L - Half thickness [m];
g - Semi empirical model Difusion approach constant;	M - Moisture content of the product [kg water/kg dry matter];
h - Semi empirical model Difusion approach constant;	M_e - Equilibrium moisture content of the product [kg water/kg dry matter];
k - Semi empirical model Difusion approach constant;	M_0 - Initial moisture content of the product [kg water/kg dry matter];
k_0 - Two term difusion model rate constant	MR - Fractional moisture ratio;
k_1 - Two term difusion model rate constant	N - Number of observations;
n - Semi empirical difusion model exponential constant	R - Ideal gas constant [8.314 J/mol·K];
t - Time [h];	R^2 - Coefficient of determination;
u - Number of terms;	$RMSE$ - Root of Mean Square Error;
z - Number of constants;	$\chi 2$ - Reduced chi-square;
D_0 - Arrhenius difusion constant;	α - Slope of ln MR-t graph.

Uysal et al., (2017). Inspection of the drying kinetics for spaghetti squash (*Cucurbita Pepa L*). *Polish Journal of Food Engineering*, *3/4*(23), 31-37.

Introduction

Although it is of great economic and environmental concern, the majority of the by-products of agricultural production and those residues wasted during and after this production can not be utilized in an efficient way.

The spaghetti squash which is cultivated in Turkey and which can not be valorized except for its seeds is included in this category of the referred agricultutral wastes. Wastes (mesocarp and epicarp) of spaghetti squash have higher carotenoid content. Consequently, spaghetti squashes are valuable sources of carotenoids.

In Turkey, spaghetti squash is cultivated widely in thrace region and in central Anatolia region in substantial amounts for nuts production. The main species which are produced particularly for this purpose are spaghetti squash (*Cucurbita pepo L.*), buttercup squash (*C. maxima*) and butternut squash (*C. moschata*). The seeds of these species might be grown for nuts production. However the mostly preferable species for cultivation is spaghetti squash (*Cucurbita pepo L.*) (Menemencioğlu et al., 2013).

A considerable amount of waste arises from nuts production of *Cucurbita pepo L* after the removal of its seeds. The total amount of skin, pulp and seeds builds up 92-95% of its composition. The scientific studies reveal that these wastes contain bioactive compounds in substantial amounts. Nevertheless, they are used as animal feed and fertilizers inspite of their nutritive and highly added value (Ağçam and Akyıldız, 2015). There is also a limited use of spaghetti squash since it is difficult to store this fruit for a long time due to its high moisture content. Therefore, application areas can be enhanced by drying known as one of the main food preservation methods.

Drying helps to improve the transportation and storage characteristics of the food material by the considerable reduction in its moisture content and thus prevention from microbial spoilage and the decline in the rate of other degradation reactions. Drying process should be so performed that it will lead to a minimal damage in the structure and quality of the food product (Singh and Heldman, 2015). For this reason, plenty of various dryers are designed in order to meet several requirements of drying process specific for each type of food (Yağcıoğlu, 1999).

The equipment used for drying of some fruits and vegetables in small particles can be categorized as cabinet dryers, tunnel dryers, conveyor type dryers and fluidized bed dryers (Cemeroğlu, 2011).

Drying is also a complicated process which includes both heat and mass transfer (Şahin ve Dinçer, 2005). From the engineering perspective, it is essential to comprehend the control parameters of this complicated process. The mathematical modelling of drying is applied in order to design innovative drying systems, to improve present processes and to control the whole process. A number of mathematical models can be used to define the drying process. The most common technique is known as thin layer drying. There are several types of thin layer drying reported so far in literature which describe the kinetic behaviour of agricultural products. These models can be classified as theoretical, semi-empirical and empirical (McMinn, 2006; Özdemir and Devres, 1999).

The aim of work

The aim of this paper was to investigate the drying kinetics of spaghetti squash (*Cucurbita pepo L.*). It also intends to test the conformance of thin layer models with the product, to select the model that describes the kinetic behaviour most satisfactorily and to compute the effective moisture diffusivity.

Material and methodology

The material used in this research (*Cucurbita pepo L)* was received from the producers (farmers) in the thrace region of Turkey in September 2016. The spaghetti squash samples which were provided as whole fruit were split into small pieces after the seeds were removed from the fruits. Then, these samples were stored in airtight and light resistant, laminated packages at -24°C. The frozen spaghetti squash samples were chopped to thickness of 2 mm. Additionally, they were sliced into pieces of 0.5 mm by another chopper (Cryptopeerless, United Kingdom) to achieve a more uniform and finer size distribution. The moisture analysis of the samples was carried out in a vacuum oven (WiseVen WOW-30, Germany) at 65 °C. The moisture content of spaghetti squash was determined as 93.7% ± 0.09.

Drying Methods

Drying was performed at different temperatures (40, 50, 60 and 70 °C) and air velocities (1, 1.4, 1.8 m/s) . The samples with an initial thickness of 0.6±0.2 mm and a total weight of 2000 ±5 g were placed into ten trays with the dimensions of 30x30x2 cm. The drying process and recording the relevant data started just after the ambient temperature reached the experimental conditions so that drying process becomes stable. All the data were monitored by the drying equipment at 20 minutes intervals automatically. The process was terminated when the samples reached constant weight.

In this study, a cabinet dryer (Weintek, Turkey) made of 10 trays and produced by a special design with certain customer specifications was used. The experiments were conducted in the production facility of Ege University Food Engineering Department. The equipment consists of trays, upper and lower pipes, a broiler, a fan, bottom air suction line and a heater. The trays consist of the frames having 30×30×2 cm dimensions with pores of 3×3 mm made of stainless steel. The air flow was parallel to the direction where the trays are placed. The uniform distribution of air over the trays inside the cabinet dryer was performed by an engine rotating at 10 rpm.

Examination of drying kinetics

It is assumed that the main mechanism of drying is described by liquid and/or gaseous diffusion when biological material is dried during falling rate period (Erbay, 2008). In thin layer drying models, the moisture content of the sample which is going to be dried is calculated by using a dimensionless variable defined as fractional moisture ratio (MR). The calculation of this dimensionless variable is given in Equation 1 (Midilli, 2001).

$$MR = \frac{M - M_e}{M_0 - M_e} = \frac{8}{\pi^2} \sum_{n=0}^{\infty} \frac{1}{(2u+1)^2} \exp\left(-\frac{(2u+1)^2 \pi^2 D_{eff} t}{4L^2}\right) \quad \textbf{(1)}$$

In this research, eleven semi empirical models and their equations illustrated in Table 1 were examined in order to select the best equation for the drying curves of spaghetti squash during the inspection of thin layer models.

Under the conditions where the relative humidity and ambient temperature inside the cabinet dryer do not come to a steady state, the following assumption can be made: The final moisture content of the product is not equal to the equilibrium moisture content. Hence, equilibrium moisture content (M_e) and except the first term in the series in Equation 1 are negligible. As a result, Equation 2 (Goyal et al., 2006; Erbay, 2008) can be written as follows:

$$MR = \frac{M}{M_0} = \frac{8}{\pi^2} \exp\left(\frac{\pi^2 D_{eff} t}{4\,L^2}\right) \quad \textbf{(2)}$$

Table 1. Semi-empirical thin layer drying models
Tabela 1. Pół-empiryczny model cienkiej warstwy suszenia

Model	Model Equation	References
Newton	MR = exp(-kt)	(Ayensu, 1997)
Page	MR = exp(-kt^n)	(Page, 1949)
Modified Page-I	MR = exp[-(kt)^n]	(Erbay, 2008)
Henderson & Pabis	MR = aexp(-kt)	(Pal and Chakraverty, 1997)
Logaritmic	MR = aexp(-kt) + c	(Doymaz, 2004)
Two Term	MR = aexp(-k0t) + bexp(-k1t)	(Dandamrongrak et al, 2002)
Exponential Two Term	MR = aexp(-kt) + (1-a)exp(-kat)	(Midilli and Kucuk. 2003)
Difusion	MR = aexp(-kt) + (1-a)exp(-kbt)	(Ertekin and Yaldiz, 2004)
Modified Henderson & Pabis	MR = aexp(-kt) + bexp(-gt) + cexp(-ht)	(Karathanos, 1999)
Verma	MR = aexp(-kt) + (1-a)exp(-gt)	(Yaldiz et al., 2001)
Midilli	MR = aexp(-kt^n) + bt	(Midilli et al., 2002)

The conformance of the experimental data with the semi-empirical models was tested by SPSS (version 20.0) software and conducting non-linear regression analysis. For each experiment, coefficient of determination (R^2), root of square mean error (*RMSE*) and reduced chi-square (χ^2) values are computed respectively in Equation 3 and Equation 4.

$$\chi^2 = \frac{\sum_{i=1}^{N} (MR_{pre} - MR_{obs})^2}{N - z} \quad \textbf{(3)}$$

$$RMSE = \sqrt{\left(\frac{1}{N} x \left[\sum_{i=1}^{N} (MR_{pre} - MR_{obs})^2\right]\right)} \quad \textbf{(4)}$$

The model with the highest value of coefficient of determination (R^2), and the least RMSE and the least reduced chi-square (χ^2) values has been determined as the best model for each experiment with the goodness of fit and minimum standard deviation between expected and observed values (Sarsavadia et al., 1999; Sun et al.., 2007; Lahsasni et al., 2004; Faustino et al., 2007).

Calculation of Effective Moisture Diffusivity and Activation Energy

Thin layer drying model assumes external resistance as negligible and the internal resistance at the center of the sample and takes difusion mechanism as the main determinant into consideration. In order to determine the effect of difusion, the difusion that takes place by multi mechanisms simultaneously can be described as one unique term called effective moisture diffusivity (D_{eff}). It is of great importance to calculate the D_{eff} values from the perspective of the drying behaviour and characteristics of the product (Erbay, 2008).

The D_{eff} values were found out by plotting the natural logarithm of the fractional moisture ratio (ln MR) obtained by the observed drying values versus time (Lomauro et al., 1985; Doymaz et al., 2004).

The slope of this graph (α) is used in Equation 2 and the Equation 5 given below can be obtained by this way.

$$\alpha = \frac{\pi^2 D_{eff}}{4\,L^2} \quad \textbf{(5)}$$

In order to evaluate the effect of temperature on the effective moisture diffusivity the Arrhenius equation (Equation 6) can be used (Lopez et al., 2000; Srikiatden and Roberts, 2006).

$$D_{eff} = D_0 \exp\left(-\frac{E_a}{R\,(T+273{,}15)}\right) \quad \textbf{(6)}$$

Activation energy (EA) can be calculated by the slope obtained by plotting the graph of natural logarithm of effective moisture diffusivity ($\ln(D_{eff})$), versus inversion of temperature (1/T) in 1/K units.

Results and discussion

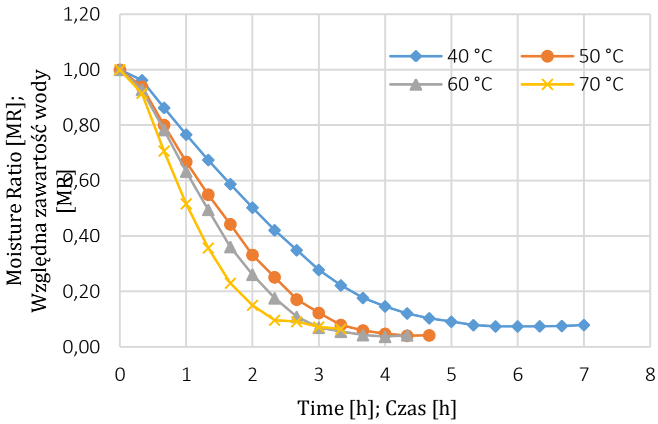

Fig. 1. Experimental moisture ratios of Cucurbita pepo L. at different drying temperatures (air velocity=1m/s)

Rys. 1. Względna zawartość wody w Cucurbita pepo L podczas suszenia w różnych temperaturach (prędkość powietrza=1 m/s)

Uysal et al., (2017). Inspection of the drying kinetics for spaghetti squash (*Cucurbita Pepa L*). *Polish Journal of Food Engineering*, *3/4*(23), 31-37.

In this research the experimental drying data obtained at 40, 50, 60, 70°C drying temperatures and air velocities of 1, 1.4 and 1.8 m/s in addition to the fractional moisture ratios were calculated according to Equation 2. As a result of these calculations, the changes in the fractional moisture ratios with time are shown in Figure 1, Figure 2, and Figure 3.

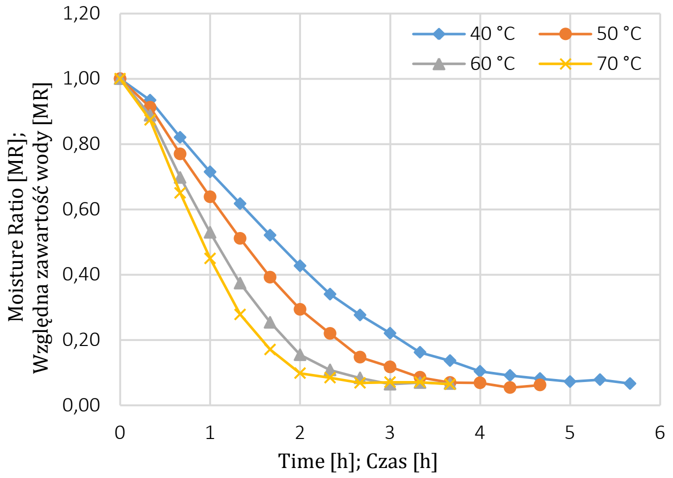

Fig. 2. Experimental moisture ratios of Cucurbita pepo L at different drying temperatures (air velocity=1.4m/s)

Rys. 2. Względna zawartość wody w Cucurbita pepo L podczas suszenia w różnych temperaturach (prędkość powietrza=1.4 m/s)

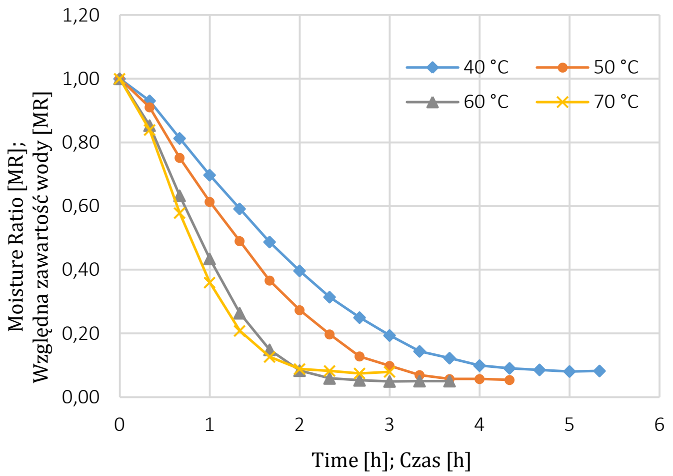

Fig. 3. Experimental moisture ratios of Cucurbita pepo L at different drying temperatures (air velocity=1.8 m/s)

Rys. 3. Względna zawartość wody w Cucurbita pepo L podczas suszenia w różnych temperaturach (prędkość powietrza=1.8 m/s)

As it can be seen from these figures, the fractional moisture ratio decreases along the drying time. This issue indicates that there is no constant rate period and drying occurs in falling rate period. The higher the drying temperature and the air velocity, the shorter the drying period. It is evident from Figure 1, Figure 2 and Figure 3, that the most rapid drying experiment was performed at 70°C with an air velocity of 1.8 m/s, while the longest drying period belonged to the experiment carried out at 40°C and with an air flow rate of 1 m/s. The results are in agreement with the findings of previous studies related to pumpkin (Doymaz, 2006), red pepper (Kavak Akpınar et al., 2002) and mango slices (Goyal et al., 2006).

Evaluation of drying kinetics

The statistical comparison made to describe the kinetic behaviour of spaghetti squash among eleven semi empirical drying models defined earlier in Table 1 is summarized in Table 2. Table 2. indicates statistical outputs such as R^2, *RMSE* and χ^2 values for each drying temperature and air velocity. The coefficients of determination (R^2) were found above 0.95. For all experiments, Midilli gave the best results in comparison to the other thin layer drying models. The coeficients of determination for Midilli model is ranging between 0.999 and 1.00, the root of square mean error (*RMSE*) values vary from 0.00255 to 0.00850 and the reduced chi-square (χ^2) values are found to be between 0.00001 and 0.00008.

Assessment of model coefficients, effective moisture diffusivity and activation energy

The model constants, coefficients and effective moisture diffusivity in relation to Midilli model which describes the kinetic behaviour of spaghetti squash most satisfactorily are given in Table 3. The value of k in this table represents the drying rate constant. It can be clearly observed that this value is directly proportional to the drying temperature. That is, the the higher drying temperature, the greater the k value. The drying rate constant is an indicator of drying rate. The rise in this value is an evidence for the increase in drying rate and the decline in drying time.

Meanwhile, the D_{eff} values in Table 3. vary from 4.15×10^{-10} to 2.04×10^{-9} m^2/s . The highest effective moisture diffusivity was obtained by the experiment performed at 70°C with an air velocity of 1.8 m/s.

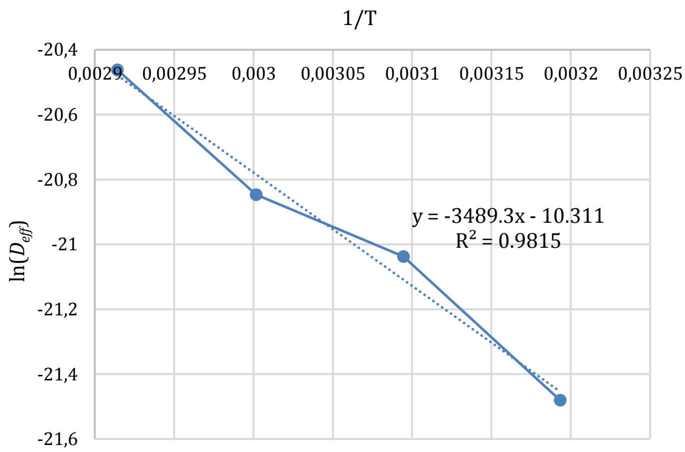

Fig. 4. Arrhenius type relationship between effective diffusivity (D_{eff}) [m^2/s] and temperature (1/K) (air velocity=1.0 m/s)

Rys. 4. Zależność zgodnie z teorią Arrheniusa pomiędzy efektywną dyfuzją (D_{eff}) [m^2/s] a temperaturą (1/K) (prędkość powietrza=1.0 m/s)

The figures of ln(D_{eff}) versus (1/T) plotted for each experimental air velocity (1, 1.4 and 1.8 m/s) are illustrated in Figure 4, Figure 5 and Figure 6.

Table 2. Statistical evaluation of drying models for Cucurbita pepo L.
Tabela 2. Statystyczna ocena modeli suszenia dla Cucurbita pepo L

Model name; Nazwa modelu	Drying temperature; Temperatura suszenia [°C]	Drying air velocity; Prędkość powietrza podczas suszenia [m/s] 1.0			1.4			1.8		
		R^2	RMSE	χ^2	R^2	RMSE	χ^2	R^2	RMSE	χ^2
MIDILLI	40	0.999	0.00740	0.00007	0.999	0.00756	0.00007	1.000	0.00633	0.00005
	50	0.999	0.00859	0.00008	1.000	0.00658	0.00006	0.999	0.00207	0.00008
	60	1.000	0.00641	0.00005	1.000	0.00650	0.00006	1.000	0.00578	0.00004
	70	1.000	0.00647	0.00006	1.000	0.00650	0.00006	1.000	0.00255	0.00001
MODIFIED PAGE	40	0.995	0.02287	0.00058	0.998	0.01522	0.00026	0.997	0.01793	0.00036
	50	0.999	0.00975	0.00010	0.998	0.01560	0.00028	0.999	0.01247	0.00018
	60	0.999	0.00911	0.00009	0.996	0.02135	0.00055	0.995	0.02363	0.00067
	70	0.995	0.02343	0.00067	0.990	0.03222	0.00125	0.990	0.03307	0.00137
EXPONENTIAL TWO TERM	40	0.995	0.02796	0.00086	0.998	0.05649	0.00359	0.997	0.01793	0.00036
	50	0.999	0.00975	0.00010	0.998	0.14592	0.02457	0.999	0.01247	0.00018
	60	0.999	0.10774	0.01250	0.996	0.17918	0.03853	0.995	0.02363	0.00067
	70	0.995	0.02343	0.00060	0.990	0.05267	0.00303	0.990	0.03307	0.00137
TWO TERM	40	0.996	0.01933	0.00041	0.998	0.01310	0.00019	0.998	0.01514	0.00026
	50	0.998	0.01479	0.00023	0.998	0.01313	0.00020	0.999	0.01175	0.00016
	60	0.998	0.01527	0.00027	0.997	0.01738	0.00036	0.996	0.02077	0.00052
	70	0.998	0.07397	0.00669	0.993	0.02321	0.00066	0.993	0.02769	0.00096
MODIFIED HENDERSON & PABİS	40	0.987	0.03719	0.00169	0.991	0.03052	0.00120	0.986	0.03728	0.00182
	50	0.989	0.26911	0.06035	0.998	0.01311	0.00023	0.990	0.03229	0.00146
	60	0.985	0.04191	0.00246	0.985	0.04085	0.00250	0.981	0.04617	0.00320
	70	0.998	12.8376	258.97853	0.978	0.04953	0.00368	0.980	0.04713	0.00370
MODIFIED HENDERSON & PABİS	40	0.987	0.03601	0.00178	0.998	0.36696	0.20199	0.998	0.10983	0.01864
	50	0.989	0.56977	0.34783	0.989	0.03371	0.00189	0.998	0.08683	0.01319
	60	0.985	0.04175	0.00305	0.985	0.04048	0.00328	0.992	0.02957	0.00175
	70	0.981	0.04593	0.00464	0.999	0.13143	0.03455	0.980	0.31407	0.24660
LOGARITMIC	40	0.985	0.48725	0.27490	0.990	0.03162	0.00120	0.989	0.03249	0.00128
	50	0.988	0.03668	0.00144	0.988	0.59478	0.44221	0.989	0.03431	0.00150
	60	0.983	0.60366	0.46378	0.983	0.04245	0.00240	0.979	0.04851	0.00314
	70	0.980	1.06185	1.55035	0.985	0.48725	0.27490	0.978	0.04957	0.00351
HENDERSON & PABİS	40	0.983	0.04075	0.00183	0.985	0.03852	0.00167	0.986	0.03728	0.00157
	50	0.973	0.05409	0.00314	0.982	0.04390	0.00222	0.981	0.04475	0.00234
	60	0.970	0.05859	0.00400	0.979	0.04780	0.00274	0.976	0.05075	0.00309
	70	0.972	0.05554	0.00377	0.976	0.05151	0.00318	0.978	0.04914	0.00302
VERMA	40	0.980	0.04471	0.00232	0.987	0.03684	0.00163	0.986	0.03756	0.00171
	50	0.984	0.04199	0.00189	0.985	0.03684	0.00163	0.986	0.03796	0.00183
	60	0.979	0.04947	0.00311	0.981	0. 04581	0.00280	0.977	0.05094	0.00346
	70	0.975	0.05325	0.00390	0.973	0.05401	0.00389	0.976	0.05151	0.00379
NEWTON	40	0.971	0.05299	0.00294	0.975	0.04902	0.00254	0.977	0.04744	0.00239
	50	0.960	0.06653	0.00474	0.973	0.05266	0.00297	0.972	0.05453	0.00320
	60	0.956	0.05643	0.00334	0.971	0.05624	0.00345	0.970	0.05720	0.00357
	70	0.961	0.06606	0.00480	0.969	0.05775	0.00364	0.972	0.05448	0.00297
DIFFUSION APPROACH	40	0.971	0.05299	0.00325	0.975	0.04902	0.00288	0.977	0.04744	0.00273
	50	0.960	0.06653	0.00474	0.973	0.05266	0.00347	0.972	0.05453	0.00378
	60	0.956	0.07074	0.00637	0.971	0.05624	0.00422	0.970	0.05720	0.00357
	70	0.961	0.06606	0.00600	0.969	0.05775	0.00445	0.972	0.05448	0.00424

Table 3. Model coefficients, best fitted models and calculated effective moisture diffusivities at different drying temperatures and air velocities for spaghetti squash (Cucurbita pepo L.)

Tabela 3. Współczynniki modelu, najlepiej dopasowane modele i obliczone skuteczne dyfuzje wilgoci w różnych temperaturach suszenia i prędkości powietrza dla dyni makaronowej (Cucurbita pepo L.)

Air velocity; Prędkość powietrza [m/s]	Drying temperature; Temperatura suszenia [°C]	Model coefficients; Współczynniki modelu a	k	n	b	Effective Moisture Diffusivity (D_{eff}); Skuteczność dyfuzji wilgoci (D_{eff}) [m²/s]
1.0	40	0.995	0.255	1.54	0.009	4.689×10^{-10}
	50	0.998	0.390	1.545	0.003	7.302×10^{-10}
	60	0.997	0.456	1.638	0.006	8.836×10^{-10}
	70	1.005	0.699	1.649	0.019	1.298×10^{-9}
1.4	40	0.993	0.327	1.4667	0.008	7.156×10^{-10}
	50	0.994	0.458	1.503	0.009	1.298×10^{-9}
	60	0.997	0.675	1.568	0.015	1.643×10^{-9}
	70	1.000	0.859	1.636	0.020	2.028×10^{-9}
1.8	40	0.995	0.361	1.47	0.011	4.154×10^{-10}
	50	0.997	0.492	1.482	0.007	7.302×10^{-10}
	60	0.995	0.887	1.615	0.014	1.490×10^{-9}
	70	1.000	1.104	1. 603	0.027	2.045×10^{-9}

Uysal et al., (2017). Inspection of the drying kinetics for spaghetti squash (*Cucurbita Pepa L*). *Polish Journal of Food Engineering*, *3/4*(23), 31-37.

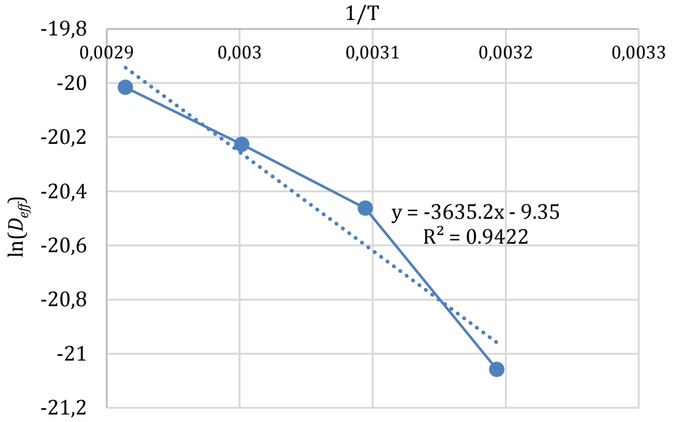

Fig. 5. Arrhenius type relationship between effective diffusivity (D_{eff}) [m²/s] and temperature (1/K) (air velocity=1.4 m/s)

Rys. 5. Zależność zgodnie z teorią Arrheniusa pomiędzy efektywną dyfuzją (D_{eff}) [m²/s] a temperaturą (1/K) (prędkość powietrza=1.4 m/s)

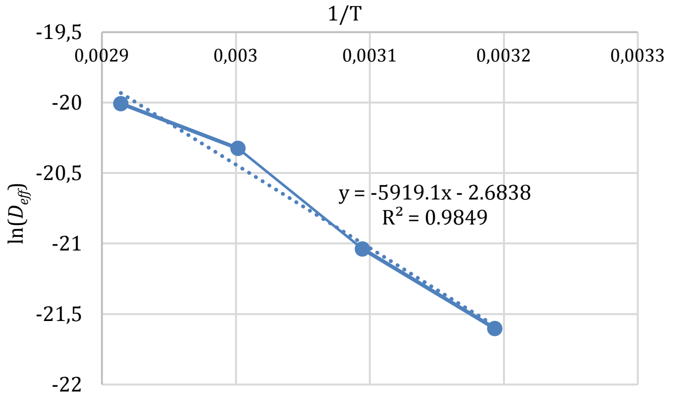

Fig. 6. Arrhenius type relationship between effective diffusivity (D_{eff}) [m²/s] and temperature (1/K) (air velocity=1.8 m/s)

Rys. 6. Zależność zgodnie z teorią Arrheniusa pomiędzy efektywną dyfuzją (D_{eff}) [m²/s] a temperaturą (1/K) (prędkość powietrza=1.8 m/s)

The activation energy and Arrhenius diffusivity constants (D_0) calculated by plotting the graphs in Figure 4, Figure 5 and Figure 6 are summarized in Table 5.

Table 4. D_0 and E_a values determined from diffusivity data

Tabala 4. Wartości D_0 i E_a wyznaczone z danych dyfuzyjności

Air velocity; Prędkość powietrza [m/s]	E_a [kj/mol]	D_0 [m² /s]
1	29.01004	$3.32 \cdot 10^{-05}$
1.4	30.22305	$8.7 \cdot 10^{-05}$
1.8	49.211	0.068

Conclusion

The spaghetti squash samples were dried at 40, 50, 60, 70°C with different air velocities of 1; 1.4 and 1.8 m/s until the attainment of constant weight. One might conclude that drying temperature and air velocity significantly influence the drying time and drying rate constant.

In accordance with the data related to drying, eleven kinetic models within the framework of thin layer drying model concept were evaluated. Consequently, the best model was determined as Midilli whose R^2 values range between 0.999 and 1.000 whose RMSE values vary from 0.00255 to 0.00850 and whose χ^2 values are changing between 0.00001 and 0.00008. The effective moisture difusivity was computed and it was determined that effective moisture diffusivity is directly proportional to drying temperature. Activation energy is also calculated by the Arrhenius theory.

References

Ayensu, A. (1997). Dehydration of food crops using a solar dryer with convective heat flow. *Solar Energy*, *59*(4–6), 121–126. DOI:10.1016/S0038-092X(96)00130-2.

Ağcam, E., Akyıldız, A. (2015). Siyah Havuç Posasından Antosiyaninlerin Ekstraksiyonuna Farklı Çözgen Ve Asit Konsantrasyonlarının Etkileri. Gıda 40.

Cemeroğlu, B. (2011). *Meyve ve Sebze İşleme Teknolojisi, 1. Baskı*, İstanbul, Nobel Yayınevi. ISBN 978-975-98578-4-4.

Dandamrongrak, R., Young, G., Mason, R. (2002). Evaluation of Various pre-treatments fort he dehydration of banana and selection of Suitable Drying Models. *Journal of Food Engineering*, 95, 139-146. DOI:10.1016/S0260-8774(02)00028-6

Doymaz, I., Gorel, O., Akgun, N.A. (2004). Drying characteristics of the solid byproduct of olive oil extraction. *Biosystem Engineering, 88*, 213–219. DOI: 10.1016/j.biosystemseng.2004.03.003.

Doymaz, I. (2004). Effect of drying treatment on air drying of plums. *Journal of Food Engineering*, *64*(4), 465–470. DOI:10.1016/j.jfoodeng.2003.11.013.

Doymaz, I. (2006). The kinetics of forced convective air-drying of pumpkin slices. *Journal Of Food Engineering 79*, 243–248. DOI:10.1016/j.jfoodeng.2006.01.049.

Erbay, Z. (2008). *The ınvestigation of modelling, optimization and exergetic analysis of drying of olive leaves.* MSc, Ege University, İzmir, Turkey.

Ertekin, C. Yaldiz, O. (2004). Drying of eggplant and selection of a suitable thin layer drying model. *Journal of Food Engineering*, *63*, 349–359. DOI:10.1016/j.jfoodeng.2003.08.007.

Faustino, J.M.F., Barroca, M.J., Guine´, R.P.F. (2007). Study of the drying kinetics of green bell pepper and chemical characterization. *Food Bioproducts Process, 85*(C3), 163–170. DOI: 10.1205/fbp07009.

Goyal, R.K., Kingsly, A.R.P., Manikantan, M.R., Ilyas, S.M. (2006). Thin-layer Drying kinetics of raw mango slices. *Biosystems Engineering*, *95*(1), 43–49. DOI: 10.1016/j.biosystemseng.2006.05.001.

Karathanos, V.T. (1999). Determination of water content of dried fruits by drying kinetics. *Journal of Food Engineering*, *39*, 337-344. DOI:10.1016/S0260-8774(98)00132-0.

Kavak-Akpınar, E., Bicer, Y., Yildiz, C. (2002). Thin layer drying of red pepper. *Journal of Food Engineering, 59*, 99–104. DOI: 10.1016/S0260-8774(02)00425-9.

Lahsasni, S., Kouhila, M., Mahrouz, M., Idlimam, A., Jamali, A. (2004). Thin layer convective solar drying and mathematical modelling of prickly pear peel (*Opuntina ficus indica*). *Energy, 29*, 211–224. DOI: 10.1016/j.energy.2003.08.009.

Lomauro, C.J., Bakshi, A.S., Labuza, T.P. (1985). Moisture transfer properties of dry and semimoist foods. *Journal of Food Science, 50,* 397–400. DOI: 10.1111/j.1365-2621.1985.tb13411.x.

Lopez, A., Iguaz, A., Esnoz, A., Virseda, P. (2000). Thin layer drying behaviour of vegetable wastes from wholesale market dry. *Technology, 18,* 995–1006. DOI: 10.1080/07373930008917749.

McMinn, W.A.M (2006). Thin layer modeling of the convective, microwave, microwave-convective and microwave-vacuum drying of lactose powder. *Journal of Food Engineering*, *72*, 113–123.

Menemencioğlu, Y.E., Emre, U., Candemir, A., Gülşen, O. (2013). Kayseri'de çerezlik kabak üretiminin sosyo-ekonomik, yetiştiricilik ve pazarlama durumu açısından incelenmesi. *Erciyes Üniversitesi Fen Bilimleri Enstitüsü Dergisi, 29*(3), 220-226.

Midilli, A. (2001). Determination of pistachio drying behaviour and conditions in a solar drying system. *International Journal of Energy Research*, *25*, 715–725. DOI: 10.1002/er.715.

Midilli, A., Kucuk, H. (2003). Mathematical modeling of thin layer drying of pistachio by using solar energy. *Energy Conversion and Management*, *44*(7), 1111–1122. DOI: 10.1016/S0196-8904(02)00099-7.

Midilli, A., Kucuk, H., Yapar, Z. (2002). A new model for singlelayer drying. *Drying Technology*, *20*, 1503-1513. DOI: 10.1081/DRT-120005864.

Overhults, D.G., White, G.M., Hamilton, H.E., Ross, I.J. (1973). Drying soybeans with heated air. *Transaction of the ASAE, 16*, 112-113. DOI:10.13031/2013.37459.

Özdemir, M., Devres, Y.O. (1999). The thin layer drying characteristics of hazelnuts during roasting. *Journal of Food Engineering, 42*, 225–233. DOI:10.1016/S0260-8774(99)00126-0.

Page, G.E. (1949). Factors *influencing the maximum rate of air drying shelled corn in thin-layers*. MSc, Purdue University, West Lafayette, IN

Pal, U.S., Chakraverty, A. (1997). Thin layer convection drying of mushrooms. *Energy Conversion and Management, 38*(2), 107–113. DOI:10.1016/0196-8904(96)00020-9.

Sahin, A.Z., Dincer, I. (2005). prediction of drying times for irregularshaped multi-dimensional moist solids. *Journal of Food Engineering*, *71*, 119–126. DOI: 10.1016/j.jfoodeng.2004.10.024.

Sarsavadia, P.N., Sawhney, R.L., Pangavhane, D.R., Singh, S.P. (1999). Drying behaviour of brined onion slices. *Journal of Food Engineering*, *40*, 219–226. DOI: 10.1016/S0260-8774(99)00058-8.

Singh, R.P., Heldman, R.D. (2015). *İntroduction to Food Engineering.* 5 th ed. New York, USA. ISBN 978-605-320-151-9.

Srikiatden, J., Roberts, J.S. (2006). Measuring moisture diffusivity of potato and carrot (core and cortex) during convective hot air and isothermal drying. *Jornal of Food Engineering*, *49*, 143–152. DOI: 10.1016/j.jfoodeng.2005.02.026.

Sun, J., Hu, X., Zhao, G., Wu, J., Wang, Z., Chen, F., Liao, X. (2007). Characteristics of thin-layer infrared drying of apple pomace with and without hot air pre-drying. *Food Science Technol.ology International, 13,* 91–97. DOI: 10.1016/j.jfoodeng.2005.02.026.

Yağcıoğlu, A. (1999). *Tarım Ürünlerinde Kurutma Tekniği.* Ege Üniversitesi Ziraat Fakültesi Yayınları, İzmir.

Yaldiz, O., Ertekin, C., Uzun, H.I. (2001). Mathematical modeling of thin layer solar drying of sultana grapes. *Energy*, *26*, 457–465. DOI:10.1016/S0360-5442(01)00018-4.

Fikret Pazir
Ege University Food Engineering Department,
Bornova-Izmir, Turkey
e-mail: *fikret.pazir@gmail.com*

Uysal et al., (2017). Inspection of the drying kinetics for spaghetti squash (*Cucurbita Pepa L*). *Polish Journal of Food Engineering*, *3/4*(23), 31-37.