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Modeling of drying characteristics of pomelo (*Citrus Maxima*) peel

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Abstract: Drying is a technique frequently used for agricultural food products to preserve them in long time periods. In this work, drying characteristics of Pomelo fruit (*Citrus Maxima*) peel for different drying techniques as microwave drying (MW), forced convection drying (FC) and freeze drying (FD) were determined. Experiments were conducted for two slab thicknesses (1 cm and 0.5 cm) in albedo part of the fruit peel. In addition, activation energy and effective diffusivity values also color properties were calculated for different drying techniques in both sizes. For FC, MW, and FD, drying times were determined as 34 min, 24 min, 410 min for thin slabs and 44 min, 30 min and 540 min for thick slabs, respectively. 0.5 cm thick peels had lower moisture content in a shorter drying period and when the slice thickness was reduced, the drying rate was increased nearly by 25%. By mathematical modelling with 11 different thin layer models, the best fitted kinetics models were found as Logarithmic, Diffusion Approach and Modified Henderson & Pabis models. At constant thickness, the highest effective diffusivity values were determined for the MW drying (1.925×10^{-8} for thin slab, 7.295×10^{-8} for thick slab). As for the color measurements, L*, a*, b* values generally have significant differences from fresh pomelo peel samples that the closest values to the fresh samples were obtained from freeze drying experiment.

Keywords: Pomelo peel, freeze drying, modeling, color change.,

Pomelo (*Citrus Maxima*) Kabuğu Kuruma Karakteristiğinin Modellenmesi

Öz: Kurutma, özellikle tarım ürünlerinin uzun süreli muhafazasında yaygın olarak kullanılan bir yöntemdir. Bu çalışmada, zorlanmış taşınımla kurutma (FC), dondurularak kurutma (FD) ve mikrodalga kurutma (MW) tekniklerinin iki farklı ürün kalınlığında (1 cm ve 0,5 cm) pomelo meyvesi (*Citrus Maxima*) kabuğunun kurutma özellikleri üzerine etkileri incelenmiştir. Ayrıca, aktivasyon enerjisi, etkin difüzivite değerleri ve renk özellikleri de her iki boyutta farklı kurutma teknikleri için hesaplanmıştır. Kabukların kuruma süresi MC, FC ve FCD yöntemlerine göre ince örnekler için sırasıyla 24 dakika, 34 dakika, 410 dakika, kalın örnekler için ise sırasıyla 30 dakika, 44 dakika ve 540 dakika olarak hesaplanmıştır. 0,5 cm kalınlığındaki örnekler daha kısa bir kuruma süresinde daha düşük nem içeriğine ulaşmış, dilim kalınlığı azaldığında kurutma hızı yaklaşık %25 artmıştır. 11 farklı ince tabaka modeli ile matematiksel modellemede en uygun kinetik modeller Logaritmik, Difüzyon Yaklaşım ve Modifiye Henderson ve Pabis modelleri olarak belirlenmiştir. Sabit kalınlıkta en yüksek etkin difüzivite değerleri MW için belirlenmiştir (ince dilim için $1{,}925 \times 10^{-8}$, kalın dilim için $7{,}295 \quad 10^{-8}$). Renk ölçümleri sonucunda, L*, a*, b* değerlerinin taze pomelo kabuğu numunelerinden önemli ölçüde farklı olduğu saptanmış, taze ürüne en yakın renk değerleri ise dondurarak kurutma yöntemiyle elde edilmiştir.

Anahtar kelimeler: Pomelo kabuğu, dondurarak kurutma, modelleme, renk değişimi.

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1. Introduction

Pomelo fruit (*Citrus Maxima*) is one of the largest and most preferred species in the Rutaceae (Citrus) family, due to its nutritional value and special taste. Pomelo fruit is usually consumed as fresh fruit or fruit juice which can be used in various alcoholic and non-alcoholic beverages; or the peel of this fruit can be sugared. There is also medical use due to its beneficial effects on health [1]. The citrus family by-products have potential to be used as ingredient in functional healthy foods and also good sources of pectin, flavonoids and antioxidants which make them beneficial to health and contribute some functional and technological properties [2-4]. Besides their dietary fiber and low-calorie content, citrus fruits are determined to well-fermentable in colon with high water holding capacities [5]. Citrus peel generally divided into two parts as albedo and flavedo which are the inner and outer parts, respectively. Albedo part constitute nearly 30% of the total weight and is characterized with its spongy and porous tissue. Despite the exploited benefits of this fruit, the peel is generally discarded and may lead to some environmental problems [3]. It should be taken into consideration that these high number of by-products may be utilized in some useful industrial applications.

Food products rapidly begin to deteriorate after harvesting because of their respiratory activities. There are many ways to enhance the durability of the harvested crops, as drying, which is one of the earliest preservation methods that lowered the moisture content to a certain level and preserving technological, microbial and nutritional values of the product. The main goal of this method is to decrease or remove the free water, stop or limit the biochemical and microbial reactions, also to preserve food products from deteriorating for extensive time intervals [6-7]. Freeze drying is based upon the removal of moisture from the frozen sample by sublimation. This technique is an extensively used process to get well-qualified and valuable dehydrated agricultural products but it has low dehydration rates which increase the expenses and slow down the process [8]. Like forced convection and freeze drying, microwave drying has been one of the most popular drying methods, recently. In this method the main principle is conversion of the thermal energy to the electromagnetic energy by affecting the polar molecules and water evaporation rates. This method reduces the drying time up to 50% which the significant energy savings are provided [9-10]. In thin layer drying, the samples which subjected to drying medium is placed as a thin layer. There are many of experimental, semi-experimental and theoretical models that introduce the drying characteristics of food products [11-16]. The mathematical modelling of the drying curves is essential to increase the efficiency of the systems [17].

Although several studies on pomelo fruit drying have been taken part in literature, there is limited information exists which the influences of various drying techniques on thin layer kinetics and the color properties of pomelo fruit peels were examined. The main purposes of this study are i) determination of the moisture ratios, moisture contents and drying rates of pomelo peels for two different thicknesses and three different drying techniques as MW, FC and FD ii) estimation of experimentally obtained drying data with 11 different drying models and choosing the most compatible model with the experimental results iii) comparison of the color properties for dried samples peel and selection of the most suitable method in terms of color changes iv) observation of the activation energy and effective moisture diffusivities and comparison for each drying condition. The framework of this study is schematically given in Fig. 1.

2. Materials and methods

2.1. Experimental setup

In this work, pomelo peels were dried by FD, MW and FC methods. Experiments were carried out in Ankara Province, Turkey. The FD process was performed with a freeze dryer (Biobase-

Biodustry, BK-FD12, China) and FC drying was performed with a convective dryer (JT 369/SL, Whirlpool Corp, Benton Harbor, MI). The loss of the sample weight with time was measured with a digital balance (XS6002S, Mettler Toledo model Excellence, USA) located in the center of drying medium which had a capacity and accuracy of 6100±0.01 g.

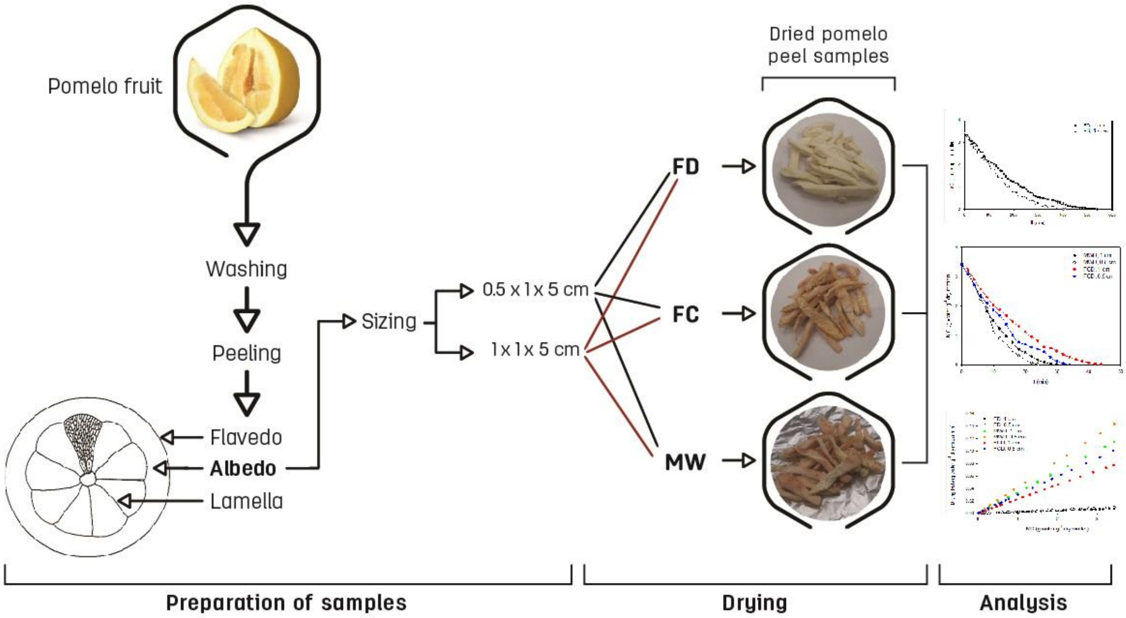

Figure 1. The framework of the study.

2.2. Preparation of pomelo peel samples and drying

Fresh pomelo fruit was taken from a local market in Ankara, Turkey. The samples then washed and the spongy albedo part of the peel was removed which cut into 5x1x0.5 cm and 5x1x1 cm slabs as length x width x thickness. Before the experiment, pomelo peel samples were divided into equal amounts of 50 g each for three different drying methods. Peels which are subjected to FD were frozen in deep freezer (UĞUR deep-freezer, UDD 300-BK) at -30±1°C. The mass measurements were conducted at 10 min intervals with a digital balance inside the drying chamber for FD. MW and FC experiments was performed at 350 W constant power, and at 90°C constant temperature values, respectively. In MW and FC, mass measurements were made every 2 min. Pomelo peels were dried from 3.43±0.02 g water g^{-1} dry matter to 0.02±0.003 g water g^{-1} dry matter which the difference of two measurements was less than about 1%. The rate of drying, moisture ratio and average moisture content values of drying process were determined for each method as three times. Moisture ratio (MR) value was calculated from the obtained experimental moisture content values. MR is typically defined by Eq. 1:

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

The drying rate of pomelo peel samples were determined through Eq. 2:

$$Drying\ rate = \frac{M_{t+dt} - M_t}{dt} \tag{2}$$

Which MR is the dimensionless fractional moisture content, M_e and M_0 are the equilibrium and initial moisture content values (g water g^{-1} dry matter); M_t and M_{t+dt} are the moisture content of the product at time t and t+dt (g water g^{-1} dry matter), respectively, and t represents the drying time (min).

2.3. Determination of the activation energy and the effective moisture diffusivity

Food drying processes usually contains different periods as constant and followed falling rate period. In falling rate period the moisture movement of a hygroscopic solid is stated with diffusion model [18]. Fick's second law of diffusion may be used to determine the drying rate theoretically and sufficiently commentate the drying data obtained from experiments (Eq. 3):

$$\frac{dMR}{dt} = D_{eff}\frac{d^2MR}{dx^2} \tag{3}$$

In the equation, D_{eff} represents the effective moisture diffusivity ($m^2\ s^{-1}$), t represents the drying time (s), and x is the diffusion path (m). During the calculations the shape of pomelo peels were assumed as infinite slab for simplify the calculations. Equation (4) is obtained when one-dimensional mass transfer was assumed as major mechanism occured in the slab geometry. Also these conditions were assumed:

- Moisture was uniformly distributed inside the peels at the beginning of drying,
- Diffusion coefficient was constant,
- Outer resistance to moisture transfer, also shrinkage was not significant [19-20].

When long drying times are concerned, the first term can be taken into consideration by itself and the equation is formed as Eq. 5:

$$MR = \frac{8}{\pi^2}\sum_{i=0}^{\infty}\frac{1}{(2i+1)^2}\exp\left[\frac{-(2i+1)^2 D_{eff}\pi^2 t}{4L^2}\right] \tag{4}$$

$$MR = \frac{8}{\pi^2}exp\left[\frac{-D_{eff}\pi^2 t}{4L^2}\right] \tag{5}$$

In the equation L expresses the half-thickness of peel assumed as slab (m). So as to determine the D_{eff} value, the drying time dependent change of the ln (MR) values are plotted graphically and D_{eff} value achieved via the straight line slope.

Activation energy value can be determined according to Arrhenius equation (Eq. 6) since the effective diffusivity (D_{eff}) shows an exponential change with temperature as follow:

$$D_{eff} = D_o exp\left(\frac{-E_a}{RT_{abs}}\right) \tag{6}$$

Which R and E_a represent the universal gas constant (8.314 J mol^{-1} K^{-1}) and the activation energy (kJ mol^{-1}), respectively. Also, D_0 represents the reference diffusion coefficient ($m^2\ s^{-1}$) and T_{abs} was the absolute temperature (K) [21]. The E_a parameter can be estimated via the slope of the ln(D_{eff}) versus T^{-1} graph.

Since the ambient temperature does not change and can not be measured in microwave dryer it is not possible to mention a temperature value. Instead, the use of equations that define the relation between the MD force values and the diffusion coefficient (Eq. 7) has also started to appear in the literature [22]:

$$D_{eff} = D_0 exp\left(\frac{-E_a m}{P_m}\right) \tag{7}$$

Which m and W represent the weight of the dried sample (g) and level of the MW power, respectively.

2.4. Determination of the thin layer characteristics

In this study, widely used 11 different semi-theoretical thin layer equations which are mostly used in the literature were selected and stated in Table 1. The drying kinetics of the peels were modeled by testing the compatibility of the pomelo peel samples with these equations and the experimental drying results. Then, the most suitable model among eleven different models for each drying methods and thickness were determined.

Table 1. Mathematical thin layer drying models*

Model	Model Equation	Reference
Lewis	MR=$e^{(-k*t)}$	[23]
Page	MR=$e^{(-k*t^n)}$	[24]
Modified Page	MR=$e^{(-(k*t)^n)}$	[25]
Henderson and Pabis	MR = $a*e^{(-k*t)}$	[26]
Modified Henderson & Pabis	MR = $a*e^{(-k*t)}+b*e^{(-g*t)}+c*e^{(-h*t)}$	[27]
Midilli	MR =$a*e^{(-k*t^n)}+b*t$	[11]
Logarithmic	MR =$a*e^{(-k*t)}+c$	[28]
Two Term	MR =$a*e^{(-k*t)}+b*e^{(-k*t)}$	[29]
Two Term Exponential	MR = $a*e^{(-k*t)}+(1-a)*e^{(-k*a*t)}$	[30]
Diffusion Approach	MR = $a*e^{(-k*t)}+(1-a)*e^{(-k*b*t)}$	[31]
Verma	MR =$a*e^{(-k*t)}+(1-a)*e^{(-g*t)}$	[32]

*****a,b,c,k,g,h,n: Drying constants.

2.5. The color measurement

Color properties also change more or less in the drying like other processes applied to food and it is generally observed during the drying process. The change of the color characteristics of samples were investigated by predicting the chroma, hue angle, color difference (ΔE) and deltaChroma (ΔC) values (Eqs. 8- 11).

$$E=\sqrt{(\Delta L^*)^2+(\Delta a^*)^2+(\Delta b^*)^2} \quad (8)$$

$$\Delta C=\sqrt{(\Delta a^*)^2+(\Delta b^*)^2} \quad (9)$$

$$C=\sqrt{a^{*2}+b^{*2}} \quad (10)$$

$$Hue\ Angle = tan^{-1}\left(\frac{b^*}{a^*}\right) \quad (11)$$

In the equations ΔL*, Δa*, Δb* represent the difference in the color parameters between the fresh and dried samples. CIE L*, a*, b* parameters were evaluated by using a color measuring device (Minolta, CR-300, Japan) from the center surface point of the pomelo peel slabs before and after the drying process, and the changes on the color parameters were determined.

2.6. Statistical Evaluation

The statistical evaluations of the results were achieved by using SPSS package program (SPSS, Ver. 20, 2011). The statistical parameters were R^2 (regression coefficient), chi-square (X^2) and root mean square error (RMSE) were determined to investigate correlation of the selected drying curve models with the empirical results (Eqs. 12, 13). That is supposed the R^2 is close to 1 as the main compliance value. Also, reduced χ^2 and RMSE values were also calculated, and these values were considered as secondary indicators of compliance.

$$\mathrm{RMSE}=\left[\frac{1}{N}\sum_{i=1}^{n}(MR_{prd,i}-MR_{exp,i})^2\right]^{0.5} \tag{12}$$

$$\chi^2=\frac{\sum_{i=1}^{n}(MR_{exp,i}-MR_{prd,i})^2}{N-n} \tag{13}$$

MR_{exp} is the moisture value measured in the experimental observation, MR_{prd} is the moisture value expected in the model, n and N represents the number of model coefficients and observations, respectively.

3. Results and Discussions

3.1. Drying rate and moisture ratio

The MC-varying drying rate graphs of the pomelo peel samples for different thicknesses and drying methods are given for MW and FC in Fig. 2 and for FD in Fig. 3. As seen in these graphs, MC values initially reduces swiftly after that slowly decreases with increasing time which means the bigger amount of the water was removed at the initial parts of experiments and declined over time. Also, it is stated that peel thickness and drying method effects the total drying time significantly and time needed for drying was increased proportionally with the enhanced peel thickness. According to Fig. 2 and Fig. 3, 0.5 cm thick peels had lower moisture content values in a shorter drying period than the 1 cm thick cuts. It can be said that drying gets faster because of the decreases amount of water carried by the reduced quantity of the sample. Compared to FC and MW methods, significant increase in drying time approximately 10 times higher and more was observed for FD method. Also, drying time of were calculated as about 24 min, 34 min, 410 min for thin slabs and 30 min, 44 min and 540 min for thick slabs for MW, FC and FD, respectively.

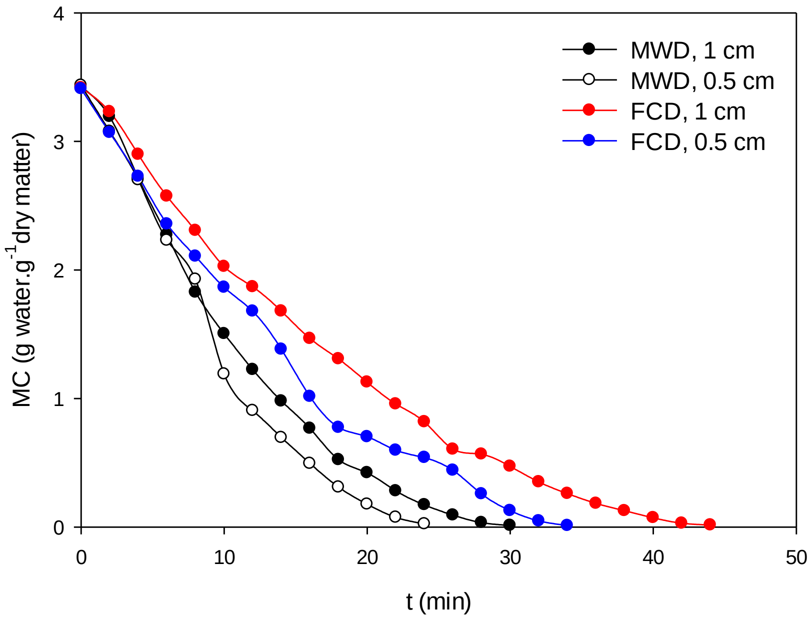

Figure 2. Time-dependent change of the MC values for MW and FC

When the results are examined, it has been observed that there is a distinct impact of the various drying methods and the thickness of the product on the drying rate. Impact of drying methods, thickness and MC on the drying rate of pomelo peels are given in Fig. 4. According to this, constant drying rate period is not exist that the drying procedure was situated in falling rate period. The reason of this may be through the inner layers of the peels which did not supply a stable amount of water in the certain drying period.

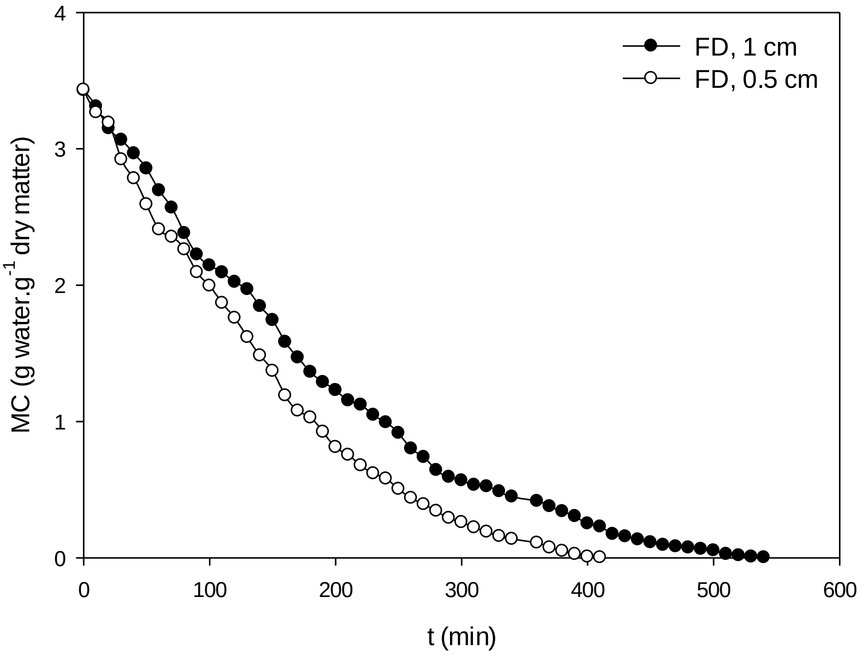

Figure 3. Time-dependent change of the MC values for FD

This also demonstrates in the drying experiments moisture diffusion behave as the main mechanism in the sample. Similar results were observed in some other studies [33-35]. Also, the faster drying rates might be associated with inner heat generation of the pomelo peel samples. According to the Fig. 4, drying rate decreased through drying time and the decreased amount of the water in the product. When the slice thickness is reduced by half, the drying rate has increased nearly by 25%. Reduced product thickness reduces the distance the water will pass with diffusion and increases the surface area per unit volume which is exposed to drying.

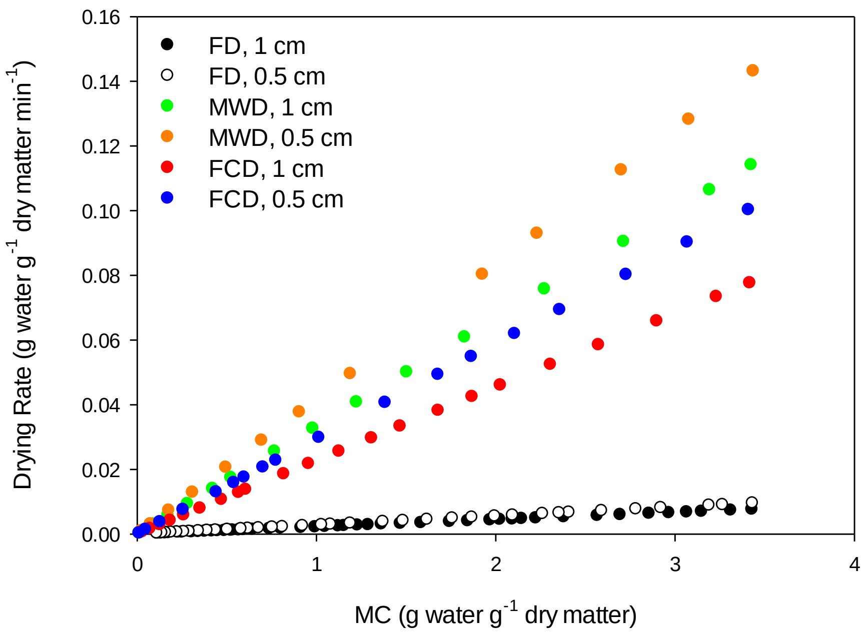

Figure 4. Effect of drying methods and MC on the drying rate of pomelo peels.

For this reason, thinner sliced food products generally dry up faster [36]. Similarly, there are other studies which observed that the drying rate is reduced by increasing sample thickness [37-38]. Compared to other methods MW resulted in shortest drying times. MW drying provides easier removal of large amount of moisture and causes lower drying time. For different food products, similar results were determined for eggplant [36], pomegrate arils [39] and jujube [40] in the literature.

3.2. Drying characteristics

Statistical findings of the best fitted three thin layer models which well-express the drying behavior of dried samples were presented in Table 2. Nonlinear regression analyses are used to calculate the coefficients for all drying models. The model coefficients are given in Table 2 for dried pomelo peel samples under different conditions.

Table 2. Statistical results of the thin layer models that best express the drying behavior of pomelo peels

	Model	Model Constants	R^2	RMSE	X^2
MW-1 cm	Logarithmic	k=0.001, c=-0.194, a=1.247	0.995	0.06992	0.00782
	Two Term	k=0.001,c=0.008,a=1.056,b=0.009	0.995	0.22541	0.10162
	Diffusion Approach	k=0.004, b=0.984, a=-61.995	0.993	0.07851	0.00771
FC-1 cm	Henderson and Pabis	k=0.0010, a=0.0010	0.981	0.07773	0.00787
	Logarithmic	k=0.001, c=-0.225, a=1.2520	0.998	0.22255	0.07439
	Diffusion Approach	k=0.002, b=0.98, a=-35.751	0.994	0.05515	0.00466
FD-1 cm	Modified Henderson and Pabis	k=0.0001, g=0.0001, h=0.0001, a=0.359, b=0.359, c=0.359	0.986	0.09222	0.02552
	Two Term	k=0.0001,c=0.0001,a=0.539,b=0.539	0.969	0.09200	0.01524
	Diffusion Approach	k=0.0001, b=0.966, a=-20.269	0.980	0.42228	0.26748
MW-0.5 cm	Logarithmic	k=0.001, c=-0.225, a=1.252	0.998	0.11096	0.01969
	Diffusion Approach	k=0.004, b=0.984, a=-61.995	0.993	0.23384	0.08749
	Two Term	k=0.001,c=0.001,a=0.54,b=0.54	0.969	0.27838	0.15499
FC-0.5 cm	Logarithmic	k=0.001, c=-0.256, a=1.272	0.998	0.11358	0.01843
	Henderson and Pabis	k=0.001, a=1.067	0.977	0.13144	0.02159
	Diffusion Approach	k=0.002, b=0.984, a=-46.065	0.992	0.06739	0.00649
FD-0.5 cm	Two Term	k=0.0001,c=0.0001,a=0.543,b=0.543	0.983	0.15974	0.04253
	Diffusion Approach	k=0.0001, b=0.984, a=-46.362	0.996	0.54922	0.43093
	Modified Henderson and Pabis	k=0.0001, g=0.0001, h=0.0001, a=0.362, b=0.362, c=0.362	0.986	0.09222	0.02552

When the results were examined, it was found that three different models well-matched with the experimental results. As seen in the table R^2 values were in 0.969-0.998, χ^2 values were in 0.005-0.431 and RMSE values were in 0.055-0.549 intervals. Accordingly, best fitted model for MW and FC drying methods with both 0.5 cm and 1 cm thicknesses is Logarithmic model. For the dried sample with 0.5 cm slice thickness in FD, Diffusion model was chosen as the most compatible model. Also, for 1 cm sliced thickness, Modified Henderson & Pabis model was determined as the most suitable model for FD.

In a study which was determined the bell pepper thin-layer drying kinetics for five different temperature levels in convective dryer, Logarithmic model was satisfactorily illustrate the drying curve of bell pepper [41]. Toğrul and Pehlivan (2004) determined that the Diffusion Approach and Modified Henderson-Pabis models are the best fitted models expressing the drying behavior of the apricots and figs; grape and plum, respectively [42].

3.3. Activation Energy and Effective Moisture Diffusivity

Effective diffusion coefficients of dried samples in MW, FC and FD for two different thicknesses were observed and the results were given in Table 3. The effective diffusion coefficients of the dried pomelo peel samples were found to be between 2.026×10^{-9} and $7.295\ 10^{-8}$ $m^2\ s^{-1}$ for different drying methods. At constant thickness, the highest effective diffusivity values has been determined for the MW drying. MW provides increasing drying rate and D_{eff} value by increasing the rate of mass transfer in thin layers of pomelo peel. In addition, it has been found that the effective diffusivity value increases with the thickness. D_{eff} value is directly relevant to the square of the sample thickness (Eq. 4). Since the amount of water in the thinner slices is smaller, the moisture concentration difference between the ambient is lower, so the transport of the sample in the fruit is slower. For this reason, the increase in thickness may lead to an increase in the effective diffusivity. Compared to FD, the obtained effective diffusion coefficients were 10 times higher for MW and FC. Since the diffusion coefficient can also be used to characterize the drying method, it is thought that the most successful drying results are taken from MW, FC and FD, respectively. In a study which apple pomace is used as sample in drying experiment the effective diffusion coefficients for four different MD powers between 150-600 W observed in the interval of $1.0465\text{-}3.6854\times10^{-8}$ $m^2\ s^{-1}$ [43]. In another study where potato slices were dried with MD, the effective diffusivity coefficients were found to vary between $0.025\text{-}3.05\times10^{-8}$ $m^2\ s^{-1}$ at power densities for four MW power densities between 5-20 W g^{-1} [44]. Dried bell peppers in a convective dryer, Taheri-Garavand et al. (2011) determined the moisture diffusion coefficient between $1.7\text{x}10^{-9}$ and $11.9\text{x}10^{-9}$ $m^2\ s^{-1}$. The data obtained from the previous literature studies were close to our experimental results [41].

The activation energy values for FC-dried samples were calculated as 52.435 and 56.791 kJ mol^{-1} for 1 cm and 0.5 cm thick sliced pomelo peel samples, respectively. Activation energy of pomelo peel samples showed slightly higher compared to bell peppers (44.49 kJ mol^{-1}) (Taheri-Garavand et al., 2011); orange skin (36.40 kJ mol^{-1}) [45]; okra (51.26 kJ mol^{-1}) [20]; orange slice (16.47–40.90 kJ mol^{-1}) [34]; in the interval of jujube (34.97 and 74.20 kJ mol^{-1}) [40] and lower by comparison of black tea (406.02 kJ mol^{-1}) [33].

Also, the activation energies of the MW-dried samples were found as 115.03 W g^{-1} for 1 cm thick peels and 124.36 W g^{-1} for 0.5 cm thick peels. Regardless of the drying methods, the activation energies decreased with the increased peel thickness. The increase in the amount of substance by increasing the thickness may caused a rise in the energies of the particles and therefore a decrease in the activation energy could be occurred. This observation is supported by several studies in the literature. For instance, the activation energies of the MD-dried samples were found as 76.5 W g^{-1} for the 5 mm thick eggplant samples and 25.4 W g^{-1} for the 10 mm thick samples [46].

Table 3. Effective diffusivity ($m^2\ s^{-1}$) values of dried pomelo peel samples

Experiment Condition	D_{eff} ($m^2\ s^{-1}$)
MW-0.5 cm	1.925×10^{-8}
MW-1 cm	7.295×10^{-8}
FC-0.5 cm	1.418×10^{-8}
FC-1 cm	5.674×10^{-8}
FD-0.5 cm	2.026×10^{-9}
FD-1 cm	8.106×10^{-9}

3.4. Color Properties

When the color properties are analyzed in Table 4, a* value is increased as against fresh sample for both two thickness levels except for FD. The L* value decreased as a consequence of all drying methods, while the b* value increased. Also, for different drying techniques different L*, a* and b* values were determined among the samples with same thicknesses. FD method was found to be more effective in preserving the Lightness (L*) value of the samples. As seen in Table 4 the Hue angle increased with drying and this increase was higher in the FD. It can be said that the color of pomelo peel samples dried with FD method is more distant from redness than other techniques.

Table 4. Color properties of pomelo peel samples before and after different drying conditions.

Color Parameters	Raw Material	Drying Condition					
		MW-0.5cm	MW-1 cm	FC-0.5 cm	FC-1 cm	FD-0.5 cm	FD-1cm
L^*	84.26 ± 0.76	65.23 ± 0.21	67.44 ± 0.32	66.58 ± 1.05	65.75 ± 0.23	72.56 ± 1.19	77.38 ± 0.63
a^*	1.70 ± 0.19	2.55 ± 0.28	2.09 ± 0.06	3.49 ± 0.14	1.96 ± 0.26	0.94 ± 0.04	0.62 ± 0.04
b^*	6.48 ± 0.61	24.13 ± 0.31	18.85 ± 0.47	22.24 ± 0.13	17.52 ± 0.33	18.63 ± 1.26	20.67 ± 0.74
C	6.69 ± 0,74	24.26 ± 1.20	18.96 ± 0.72	22.51 ± 0.56	17.60 ± 1.01	18.65 ± 0,94	20.67 ±1.12
ΔC	-	17.67 ± 0.76	12.38 ± 0.54	15.86 ± 0.82	11.03 ± 0.62	12.18 ± 0.78	14.23 ± 0.73
ΔE	-	42.84 ± 1.04	38.84 ± 1.32	40.88 ± 1.01	40.05 ± 0.93	33.95 ± 1.14	30.41 ± 1.12
Hue angle	1.31 ± 0.12	1.46 ± 0.02	1.46 ± 0.03	1.41 ± 0.03	1.45 ± 0.08	1.52 ± 0.01	1.54 ± 0.02

In Fig. 5 and Fig. 6 the column charts of other color parameters were shown as deltaChroma (ΔC), total color difference (ΔE), respectively. According to Fig. 5 and also Table 4 the ΔC value was found to be higher in MW than FC and minimum ΔC value is observed in FD. This result shows that the color saturation is higher in MW that the product becomes darker. The total color change in dried samples was observed most in MW dried samples and least in FD dried samples for the same peel thickness. Comparing the drying methods in terms of ΔC and ΔE values, it was seen that the FD caused a little less change. Similar results were observed in the literature in terms of color changes of dried pomelo peels [47].

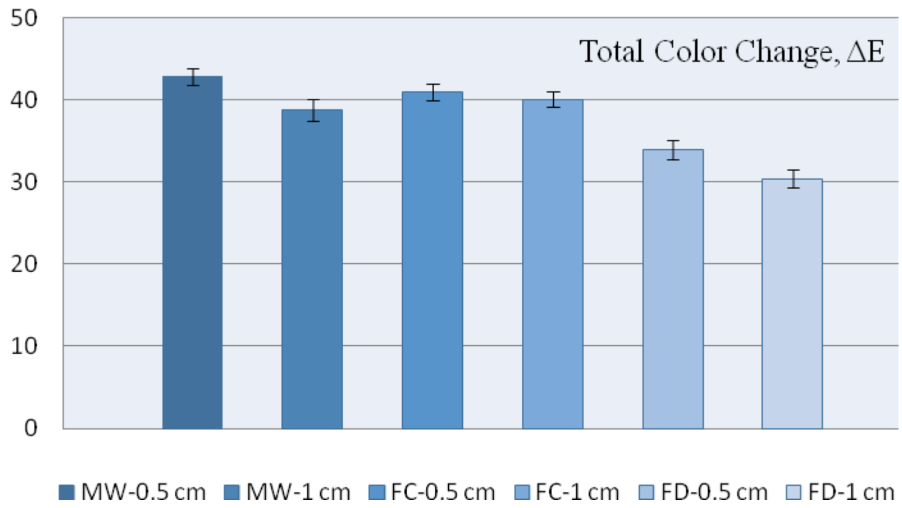

Figure 5. Effect of sample thicknesses and drying methods on the ΔE color properties of pomelo peels.

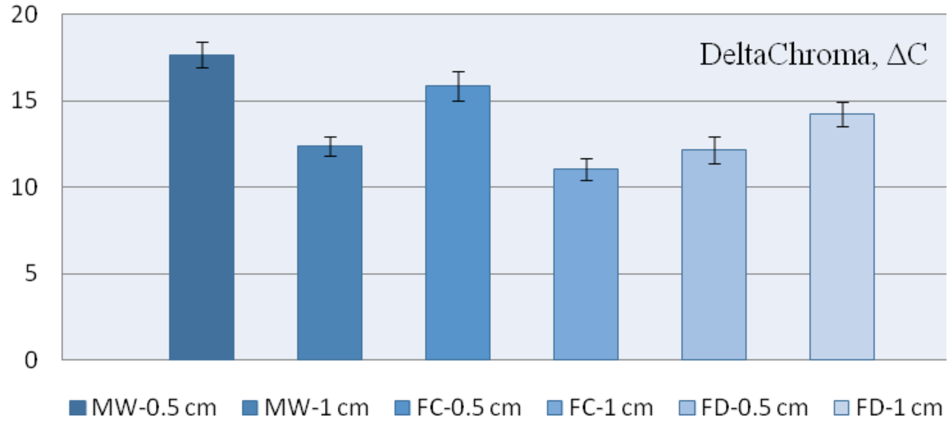

Figure 6. Effect of sample thicknesses and drying methods on the ΔC color properties of pomelo peels.

4. Conclusions

It was observed from the experimental results that for each drying method and sample thickness only the falling rate period took place similar to most of the studies in the literature. Logarithmic, Modified Henderson & Pabis and Diffusion Approach Models were most suitably models for explaining the drying of pomelo peel slices. Results indicated that drying periods and effective diffusivity coefficients of pomelo peel samples enhanced with increase in peel thickness inversely with the drying rate and Ea values. Deff value of the samples were varied between 2.026×10-9 and 7.295×10-8 m2 s-1 and also found as about 10 times higher for MW and FC methods compared to FD. The closest color parameters to the fresh product were obtained from FD method with respect to ΔE and ΔC values. As a result, when looking at all these characteristics in general, it can be seen that the closest quality feature to the fresh sample can be achieved with FD and the fastest drying can be achieved with MW. If it is evaluated in terms of drying time, it is very clear that drying with MW could be more advantageous with poorer quality characteristics compared to FD.

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