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Effective Parameters in Hot Air Drying Process on Qualitative Properties of Grapefruit (*Citrus paradise* L.) and Selection of a Suitable Mathematical Thin-Layer Drying Model

Z. Moezzi [a]***, S. Movahhed*** [b*]***, H. Ahmadi Chenarbon*** [c]

[a] Graduated Student of the Department of Food Science and Technology, College of Agriculture, Varamin-Pishva Branch, Islamic Azad University, Varamin, Iran.
[b] Associated Professor of the Department of Food Science and Technology, College of Agriculture, Varamin-Pishva Branch, Islamic Azad University, Varamin, Iran.
[c] Assistant Professor of the Department of Agronomy, College of Agriculture, Varamin - Pishva Branch, Islamic Azad University, Varamin, Iran.

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ABSTRACT: The thin-layer drying behavior of Grapefruit slices is experimentally investigated in a convective dryer and the mathematical modeling by using thin-layer drying models is performed. In the present study, tests were conducted using three air temperatures (45, 55, 65 °C), two hot air velocities (1 and 2 ms^{-1}), two-bed depth (1 and 2 cm) and three replications for each treatment. Based on the results, the best drying time was measured at 65 °C, hot air velocity of 2 ms^{-1} and bed depth of 1cm for 73 min. The calculated maximum value of effective moisture diffusivity coefficient was 7.44×10^{-8} m^2s^{-1}, and the minimum activation energy was 16.09 $kJ.mol^{-1}$, at 65 °C, hot air velocity of 2 ms^{-1} and bed depth of 1cm. In the same vein, the maximum value of vitamin C (32.03 mg. (100 g)$^{-1}$) was obtained at 55 °C, hot air velocity of 2 ms^{-1} and bed depth of 1cm. In addition, the page equation was found to give better predictions than the others. It is worth to note that the minimum value of change color (23.76) was measured at 45 °C, hot air velocity of 2 ms^{-1} and bed depth of 1cm.

Keywords: *Activation Energy, Diffusivity, Grapefruit, Hot Air Drying, Mathematical Modeling*.

Introduction

Citrus is today one of the high-income sources for producer countries. Grapefruit is one of the citrus species used as fresh fruit, concentrated juice or dried thin-layers. Grapefruit (*Citrus paradise* L.) from the *Rutacea* family is a native tree of Iran found in the north and south of this country. Grapefruit contains very important natural chemical components including phenolic compounds (mainly flavonoids) and other nutrients and non-nutrients such as vitamins, minerals, and fiber, which are essential for natural growth and the proper function of physiological systems of creatures. The pink and red species of grapefruit includes large amounts of beta carotene (Abd Ghafar *et al.*, 2010). Various processes used in converting industries turn spoiled products into products with high stability. The products are stored and transferred to consumer markets throughout the year by using these technologies and consequently, their access time increases and their nutritional value and qualitative features are protected. The storage stability of agricultural products

[*]Corresponding Author: Movahhed@iauvaramin.ac.ir

depends on physical factors including the temperature of the environment and the moisture of the product and the length of this period significantly increases by decreasing moisture or temperature or both (Ertekin and Yaldiz, 2004). Drying is defined as a process of moisture removal due to simultaneous heat and mass transfer. It is also one of the conservation methods of agricultural products, which is most often used and is the most energy-intensive process in the industry. Moreover, drying is one of the oldest methods of food preservation and is a difficult food processing operation mainly because of undesirable changes in the quality of the dried product (Lahsasni *et al.*, 2004). In other words, drying refers to the removal of moisture from products as the activity of enzymes reduces and bacteria and pathogens cannot grow and prevents food corruption. This process should make the slightest changes in the qualitative indices of the product. These indicators include physical changes such as dimensions, size, and shape of the tissue, wrinkling, hardness and chemical changes such as browning reactions, discoloration, variations in vitamins, amino acids, fats, and oxidation in materials. In drying operations, three general principles should be observed and lack of attention to any of these principles causes serious damages to the product in terms of quality and tissue. These principles include choosing the best type of dryer for the product, the best treatment in each drying mechanism, and maintaining the quantitative and qualitative properties of the product during drying (Doymaz, 2004). In the same vein, a large number of studies were conducted on drying products (Ertekin and Yaldiz, 2004; Goyal *et al.,* 2007; Zecchi *et al.,* 2011; Evin, 2012; Chen *et al.,* 2012). On the other hand, thin-layer equations describe the drying phenomena in a united way, regardless of the controlling mechanism. They have been used to estimate drying times of several products and to generalize drying curves. In the development of thin-layer drying models for agricultural products, generally the moisture content of the material at any time after it has been subjected to a constant relative humidity and temperature conditions is measured and correlated to the drying parameters (Togrul & Pehlivan, 2002). Many researches on the mathematical modeling and experimental studies have been conducted on the thin-layer drying processes of various vegetables, fruits and other agricultural products (Akpinar *et al.,* 2003; Goyal *et al.,* 2007; Evin, 2012; Ahmadi Chenarbon *et al.*, 2012). Based on the statistics, grapefruit production has increased significantly in recent years as the United States with 1, 580,000 tons of annual production was introduced as the largest producer of grapefruit in 2007, followed by China with 547,000 tons of grapefruit, South Africa, Mexico and Syria. In Iran, the grapefruit production has been 65000 tons in 2015. A high percentage of the grapefruit product content is water, which has a high metabolic activity after the harvest, leading to a quick perishable product. Therefore, it is necessary to find a way to reduce the amount of moisture and increase the shelf-life of grapefruit. Recently, there have been some studies on drying behavior of grapefruit under different drying methods such as spray-drying and freeze-drying or use of different pre-treatments such as microwave before drying to reduce the initial moisture content (George and Datta, 2002; Zhang *et al.,* 2006; Igual *et al.,* 2010; González *et al.*, 2018). According to other researches, drying of grapefruit is difficult because the dehydration of this fruit affects their content of phenols, ascorbic acid and antioxidant activity. That is why efforts should be made to reduce drying times but also to decrease the temperatures used in the drying processes to obtain better quality products (Igual *et al.,* 2010; Moraga *et al.,* 2012). However, no research, to the best of our knowledge, has been conducted on grapefruit drying, especially using hot air, which was examined in the present study.

Materials and Methods

- Drying process

The grapefruit samples were in spherical shape and the mean values of physical properties of them which were studied in this research (length, width, thickness, geometric mean diameter and mass) were 70.325 mm, 72.680 mm, 73.031 mm, 72.001mm and 198.56 g, respectively. Due to the continuity of the testing steps, all samples required for drying were prepared together and packaged in separate plastic packs and placed in refrigerator at 4 ± 1°C to prevent microbial activity. The slices (10 mm thick and 72.680 mm diameter) were cut by using an electric slicing machine (Genius carrot slicer, made in Germany). The calculated moisture of the samples before the experiment was 85 ± 2 (db %) and during the drying process the moisture of the samples decreased to 8 (db %). Three types of Kiln laboratory dryer were used to dry grapefruit slices. Drying chamber is a 40×40×50 cm container located 70 cm above the heating elements (Figure1).

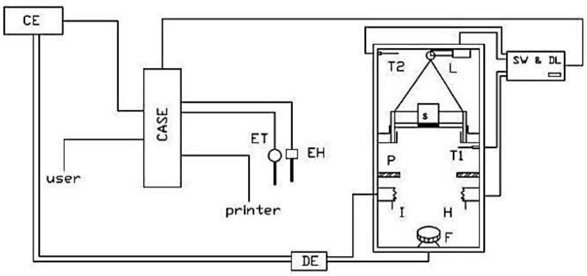

Fig.1. Experimental dryer, (F) Fan, (H) Heat generator, (S) Sample, (T1) Lower thermometer, (T2)Upper thermometer, (Sw) Switches, (DL) Data logger, (CE) Control electronic system, (DE) Electronic driver, (EH) Environment relative humidity sensor, (ET) Environment temperature sensor

Each dryer has two electric elements to generate the required heat, one of them controlled by a digital thermostat and the other controlled manually. Hot air flow is produced by a blower located under the elements, providing an adjustable flow rate in the range of 180 to 220 m^3h^{-1} using a dimmer. Two sensors are mounted in the upper and lower parts of the dryer, to measure the temperature of the drying air before and after the samples location. Prior to starting of each experiment, air temperature was adjusted by the thermostat and the dryers were activated to reach the required temperature. Data collection for thin-layer drying experiments was performed through weighing of samples at 5 min intervals using a ±0.00l g digital balance (Sartorius, model PT210, Germany). The mean value of the sample dry weight was used for calculations. Weighing of the samples continued until three consecutive readings showed the same value. Initial and final sample moisture contents were determined gravimetrically before and after the drying experiment. Moisture content of the samples was determined by drying in a vacuum dryer (model Galen Kamp) at 70 °C, 150 mbar, for 8 h (Tsami *et al.*, 1990). The velocity of drying air was adjusted to the desired level by adjusting the blower motor and measured by an anemometer (AM-4201, Lutron) with an accuracy of ±0.l ms^{-1}. During the experiments the ambient air temperature and RH variations in the laboratory were measured to be between 25 to 29 °C and 31 to 33%, respectively. Independent variables of the current research included temperature at three levels of 45, 55 and 65 °C, air velocity at two levels of 1 and 2 m/s, and bed depth at two levels 1 and 2 cm.

Given the independent factors, the total number of treatments was 12 and as the experiments were conducted in three replications, a total of 36 experimental units were tested. Table 1 indicates the treatments.

- Mathematical modeling of drying

For modeling of thin-layer drying of

grapefruit, the moisture ratio (MR) was simplified to $\frac{M_t}{M_o}$ instead of the $\frac{M_t-M_e}{M_o-M_e}$ (Ertekin and Yaldiz, 2004). As the Me value is very small compared to M_o and M_t values, the M_e value can be neglected.

Where, MR is moisture ratio (dimensionless), M_t is moisture content at time t (d.b %), Mo is initial moisture content (d.b %), and Me is equilibrium moisture content (d.b %).

In order to model the moisture content of grapefruit slices during drying, 7 experimental models, in which k, n, a, b, c, g, k_0 and k_1 were model constants, were used (Table 2).

During the modeling process, in order to fit the data, non-linear regression method was used and the aforementioned models were fitted into the data. In order to determine the reliability of the fitness, in addition to determining R^2 coefficient, 3 other factors were used (Mujumdar, 2000).

$$P-value = \frac{100}{N}\sum\frac{|M_i-M_{pre}|}{M_i} \quad (1)$$

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

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

Where,

M_i: product moisture, M_{pre}: moisture content predicted by the model, N: number of observations, n: number of model constants, MR_{exp}: the ratio of moisture in experimental data, and MR_{pre}: the ratio of predicted moisture.

Goodness of fit was determined through three indices, *P- value*, χ^2 (chi-square test), and RMSE (root mean square error) besides the coefficient of determination (R^2). Higher R^2 values and lower values for the other three indices indicate better fit.

Table1. Treatments of study

Row	Treatments	Treatment code
1	Temperature= 45˚C; Air velocity=1 m/s; Bed depth= 1 cm	C1
2	Temperature= 45˚C; Air velocity=1 m/s; Bed depth= 2cm	C2
3	Temperature= 45˚C; Air velocity=2 m/s; Bed depth= 1 cm	C3
4	Temperature= 45˚C; Air velocity=2 m/s; Bed depth= 2 cm	C4
5	Temperature= 55˚C; Air velocity=1 m/s; Bed depth= 1 cm	C5
6	Temperature= 55˚C; Air velocity=1 m/s; Bed depth= 2 cm	C6
7	Temperature= 55˚C; Air velocity=2 m/s; Bed depth= 1 cm	C7
8	Temperature= 55˚C; Air velocity=2 m/s; Bed depth= 2 cm	C8
9	Temperature= 65˚C; Air velocity=1 m/s; Bed depth= 1 cm	C9
10	Temperature= 65˚C; Air velocity=1 m/s; Bed depth= 2 cm	C10
11	Temperature= 65˚C; Air velocity=2 m/s; Bed depth= 1 cm	C11
12	Temperature= 65˚C; Air velocity=2 m/s; Bed depth= 2 cm	C12

Table2. The models that used in order to fitting the experimented data

Model	Equation	Reference
Lewis	$MR = \exp(-kt)$	(Fethi Mechloch *et al.*, 2012)
Henderson & pabis	$MR = a\exp(-kt)$	(Fethi Mechloch *et al.*, 2012)
Page	$MR = a\exp(-kt^n)$	(Barroca and Guine, 2012)
Modified Page	$MR = e\,xp(-(kt)^n)$	(Barroca and Guine, 2012)
Yagcioglu	$MR = a\exp(-kt) + C$	(Yagcioglu *et al.*, 1999)
Verma	$MR = a\exp(-kt) + (1-a)\exp(-gt)$	(Mujumdar, 2000)
Tow term model	$MR = a\exp(-k_0t) + b\exp(-k_1t)$	(Mujumdar, 2000)

- *Calculating the moisture diffusivity coefficient*

In order to calculate the amount of effective water diffusivity coefficient, Fick's second law was used (Equation 4) (Crank, 1975).

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

Where,

MR: moisture content (dimensionless), M_t: moisture amount in t (d.b %), M_0: primary moisture content (d.b %), M_e: moisture content balance (d.b %), D_{eff}: effective water diffusivity coefficient (m^2/s), L: half the sample's thickness (m), n: number of experimental data, and t: drying time(s).

Given the insignificant moisture content balance (Me=0), Equation 4 was modified as Equation 5 (Mujumdar, 2000; Dehghan Nasiri *et al.*, 2011).

$$MR = \frac{M_t}{M_0} = \frac{8}{\pi^2} \exp\left(-\frac{\pi^2 D_{eff} t}{4L^2}\right) \quad (5)$$

- *Activation energy*

In order to calculate the effect of temperature on effective water diffusivity coefficient, the Arrhenius equation (Equation 6) was used, and activation energy was also determined (Dehghan Nasiri *et al.*, 2011).

$$D_{eff} = D_{\circ} exp\left(\frac{E_a}{RT}\right) \quad (6)$$

Where,

D_{eff}: effective water diffusivity coefficient (m^2s^{-1}), D_o: pre-exponential factor (m^2s^{-1}), E_a: activation energy ($kJ.mol^{-1}$), R: universal gas constant (8.314472 $J.mol^{-1}.K^{-1}$) and T: absolute temperature (K).

- *Measurement of vitamin C*

In order to measure the amount of vitamin C or ascorbic acid of product, first 25 ml of 6% meta-phosphoric acid was added to 10 g of sample, and then 5 ml of the solution was dispersed with 3% meta-Phosphoric acid and was filtered. In the next stage, 10 ml of the filtered sample was titrated with 2, 6-dichlorophenolindophenol. Finally, the solution was pale pink color, which remained stable for 15 seconds (Anonymous, 2000).

- *Color measurement*

At the end of the drying process, the change color of samples was determined by Hunterlab device, model D25-9000. Change of color (ΔE) was estimated by using equation (7) (Albanese *et al.*, 2013).

$$\Delta E = \sqrt{(L^* - L_0^*)^2 + (a^* - a_0^*)^2 + (b^* - b_0^*)^2} \quad (7)$$

Where,

ΔE is color change, L_0^*, b_0^* and a_0^* are lightness, blueness-yellowness and greenness-redness values, respectively.

- *Statistical analysis*

In the present study, a factorial experiment was used in a completely randomized design to analyze the data. The mean comparison was conducted by Duncan's multiple range test at the probability level of α=5% by SPSS software version 14. Notably, each experiment was performed in three replicates.

Results and Discussion

- *Effect of variables on drying time*

As shown in Table 3, the maximum drying time is 149 min at 45 °C, hot air velocity of $1ms^{-1}$, bed depth of 2 cm and its minimum value is 73 min at 65 °C, hot air velocity of 2 ms^{-1} and bed depth of 1cm.

Table 3. Mean comparison of interaction between independent variable (air temperatures, hot air velocities and bed depth) on drying time of grapefruit slices

		Temperature (˚C)		
Bed depth (cm)	**Air velocity (ms^{-1})**	**45**	**55**	**65**
1	1	126±1.56^{b}	95±1.11^{d}	82±1.08^{f}
1	2	104±1.05^{c}	82±1.08^{f}	80±1.06^{f}
2	1	149±1.47^{a}	126±1.56^{b}	105±1.05^{c}
2	2	123±2.13^{b}	104±1.12^{c}	88±1.34^{e}

Different letters indicate a significant difference between means at $P<0.05$

A large number of researchers recommended that the final moisture content of all types of layers should be 8% based on dry weight in order to prevent fungal and aflatoxin contamination and declared that minimizing the moisture content of the product from the limit value leads to a decrease in final quantity and quality (Hevia *et al.*, 2002). Based on the results, an increase occurred in the moisture exit speed of the product and the drying rate due to the temperature enhancement. In other words, the higher temperature of the inlet air leads to the higher outlet moisture content of the product and the reduced drying time, due to the increase in the movement of water molecules in the product because of heat. Further, the drying time gradually decreased by increasing the inlet air velocity. The air does not penetrate the shell of the product and merely transfers the moisture from the surface of the product. In other words, the air reduces the resistance against the mass transfer from the product surface. Therefore, when the inlet air velocity is high, it surrounds the higher level of the product and the whole surface of the layers is heated and the moisture moves faster from the center towards the surface. On the other hand, through increasing the thickness of the layer, the drying time of the layers significantly increases, due to the effect of the thickness of the product mass on the amount of water existing in the total dried product, which should be evaporated. This observation is in agreement with previous researches on drying of different fruits (Doymaz and Pala, 2002; Akpinar *et al.*, 2003).

- *Evaluation of the drying model*

The moisture ratio data of grapefruit slices dried at different temperatures with different pretreatments were fitted into the thin-layer drying models. All the models gave consistently high coefficient of determination (R^2) values. This indicates that all the models could satisfactorily describe the air-drying of grapefruit slices (Table 4). But, among the thin-layer drying models, the page model obtained the highest R^2 values and the lowest P-value, χ^2 and RMSE values in the temperature and air velocity range of the study. Thus, this model may be assumed to present the thin-layer drying behavior of the grapefruit. The coefficient of correlation and results of statistical analyses are listed in Table 5. Similar findings were reported for hot air drying of apricots and rosehip (Doymaz, 2004; Erenturk *et al.*, 2004).

- *Calculation of effective moisture diffusivity*

As shown in Table 6, the maximum and the minimum moisture diffusivity coefficient calculated 7.44×10^{-8} m^2s^{-1} and 1.69×10^{-8} m^2s^{-1}, respectively.

Table 4. Correlation coefficients of the drying models at different levels of temperature (45, 55 and 65 °C), air velocity (1 and 2 ms^{-1}), and bed depth (1 and 2 cm)

Equation	R^2	$\chi2\times10^{-2}$	$RMSE\times10^{-2}$	P- value (%)
$MR = e\,xp(-kt)$	0.97	59	16	10.36
$MR = a\,\exp(-kt)$	0.97	38	18	12.77
$MR = a\,\exp(-kt^n)$	0.99	12	11	5.60
$MR = \exp(-(kt)^n)$	0.99	15	20	6.13
$MR = a\,\exp(-kt) + C$	0.95	48	33	9.45
$MR = a\,\exp(-kt) + (1-a)\exp(-gt)$	0.98	12	24	11.42
$MR = a\,\exp(-k_0t) + b\exp(-k_1t)$	0.95	27	31	18.56

Table 5. Fittings of data by page model in drying process of grapefruit slices

Temperature(°C)	Hot air (ms^{-1}) velocity	n	k	a	R^2	$\chi^2\times10^{-2}$	$RMSE\times10^{-2}$	P- value (%)
	1	0.12	0.10	0.022	0.95	9	20	10.50
45	2	0.15	0.22	0.21	0.95	10	10	8.30
	1	0.45	0.15	0.32	0.99	10	10	10.20
55	2	0.10	0.03	0.42	0.99	8	65	6.31
	1	0.45	0.22	0.22	0.98	10	22	8.12
65	2	0.14	0.17	0.45	0.99	6	7	7.03

Table 6. Mean comparison of interaction between independent variable (air temperatures, hot air velocities and bed depth) on effective moisture diffusion coefficient at drying durations (80-149 min)

Bed depth (cm)	Air velocity (ms^{-1})	Temperature (°C) 45	55	65
1	1	$(3.17\pm0.03)\times10^{-8f}$	$(4.64\pm0.03)\times10^{-8d}$	$(6.74\pm0.02)\times10^{-8b}$
1	2	$(3.74\pm0.02)\times10^{-8e}$	$(5.84\pm0.02)\times10^{-8c}$	$(7.44\pm0.03)\times10^{-8a}$
2	1	$(1.79\pm0.04)\times10^{-8i}$	$(2.47\pm0.04)\times10^{-8h}$	$(2.58\pm0.04)\times10^{-8g}$
2	2	$(1.85\pm0.04)\times10^{-8i}$	$(2.54\pm0.03)\times10^{-8gh}$	$(3.22\pm0.02)\times10^{-8f}$

Different letters indicate a significant difference between means at $P<0.05$

The results obtained have shown that internal mass transfer resistance due to presence of a falling rate-drying period controls drying time. Therefore, experimental results can be interpreted by using Fick's diffusion equation. Based on the results, the effective moisture diffusivity coefficient enhanced with increasing temperature and air velocity at a depth of 1 cm during the drying process of grapefruit slices because molecular movement and surface suction are higher in high temperature and hot air velocity. In addition, the effect of temperature was more significant. The enhancement of the temperature and inlet air velocity increased the enthalpy of the inlet air, leading to an increase in the mass and heat transfer rate, and consequently, an increase in the effective moisture diffusivity coefficient. Summarily, there are two main reasons for this phenomenon. First, as the temperature rises, the molecular movement of the water or water vapor inside the product increases and flows with more speed inside the product. Second, through increasing temperature, the equilibrium moisture content of the surface of the product decreases with drying air, leading to more decrease in the moisture of the surface in the product. In addition, the surface moisture gradient and the center of the product increase by reducing the moisture of the surface in the product and the moisture moves more rapidly inside the product and accordingly leading to an increase in the effective moisture diffusivity coefficient (Doymaz and Pala, 2002; Akgun and Doymaz, 2005).

- Calculation of effective energy activation

Based on Table 7, the maximum and the minimum activation energy calculated 41.11 kJ.mol^{-1} and 16.09 kJ.mol^{-1}, respectively.

Among the numerous interactions among particles forming a body, only a small number of them lead to the reaction. In fact, the energy of the particles in the collision should be able to weaken the bonds between the reactants and this energy is called activation energy. Actually, activation energy is the least amount of energy needed to start a reaction. Activation energy indicates the relationship between the temperature of the process and moisture diffusivity coefficient as well as the amount of energy needed to start the drying process. In the present study, the increase in the temperature and air velocity resulted in an increase in mass and heat transfer. In other words, the increase in air temperature enhanced the enthalpy of the inlet air, resulted in increasing the mass and heat transfer rate and decreasing the energy consumption (Doymaz and Pala, 2002; Akgun and Doymaz, 2005).

- Vitamin C measurement

The maximum and the minimum amounts of ascorbic acid were measured 32.03 mg (100g)$^{-1}$ and 6.8 mg (100g)$^{-1}$, respectively (Table 8).

The amount of ascorbic acid is directly related to the process time and the amount of heat exposed to the product, due to the high sensitivity of ascorbic acid to the heat. Ascorbic acid is oxidized by thermal processes and is converted to dehydroascorbic acid and other compounds. Less drying time leads to less opportunity for the occurrence of chemical decomposition reactions. In other words, the amount of vitamin C decreases with prolonged drying time, due to the oxidation of ascorbic acid, as well as the maillard reactions (Samira *et al.*, 2014).

- Change color (ΔE) measurement

As shown in Table 9, the maximum and the minimum change of color (ΔE) were measured 30.87 and 23.76, respectively.

Table 7. Mean comparison of interaction between independent variable (air temperatures, hot air velocities and bed depth) on activation energy of grapefruit slices at drying durations (80-149 min)

		Temperature (˚C)		
Bed depth (cm)	**Air velocity (ms^{-1})**	**45**	**55**	**65**
1	1	32.14±0.03^{d}	21.19±0.05^{g}	18.32±0.05^{h}
1	2	26.21±0.05^{f}	20.23±0.04^{gh}	16.09±0.03^{i}
2	1	41.11±0.04^{a}	36.35±0.03^{c}	29.02±0.02^{e}
2	2	38.20±0.05^{b}	32.18±0.03^{d}	26.30±0.04^{f}

Different letters indicate a significant difference between means at *P*<0.05

Table 8. Mean comparison of interaction between independent variable (air temperatures, hot air velocities and bed depth) on the amount of vitamin C

		Temperature (˚C)		
Bed depth (cm)	**Air velocity (ms^{-1})**	**45**	**55**	**65**
1	1	21.18±0.05^{d}	25.19±0.04^{c}	9.42±0.02^{i}
1	2	29.11±0.04^{b}	32.03±0.03^{a}	11.09±0.04^{h}
2	1	15.19±0.04^{g}	16.81±0.04^{f}	6.92±0.05^{j}
2	2	19.10±0.03^{e}	22.27±0.04^{d}	7.02±0.05^{j}

Different letters indicate a significant difference between means at *P*<0.05

Table 9. Mean comparison of interaction between independent variable (air temperatures, hot air velocities and bed depth) on the change color of grapefruit slices

Bed depth (cm)	Air velocity (ms^{-1})	Temperature (˚C) 45	55	65
1	1	24.10±0.03^{f}	25.87±0.03^{e}	28.42±0.03^{b}
1	2	23.76±0.05^{g}	24.13±0.03^{f}	28.40±0.03^{b}
2	1	27.18±0.05^{c}	28.40±0.03^{b}	30.87±0.03^{a}
2	2	25.80±0.04^{e}	26.55±0.05^{d}	29.94±0.04^{a}

Different letters indicate a significant difference between means at P<0.05

Based on the results, color is darkened at high temperatures, due to the browning reactions, protein decomposition, an increase in the amount of phosphatides without water absorption capability, an increase in the amount of sulfur and the effect of temperature on the other non-glyceride compounds such as phosphatides and existing pigments, especially chlorophyll and xanthophylls. An increase in temperature leads to an increase in the amount of browning reactions and the production of dark pigments. Increasing the temperature definitely accelerates the maillard reaction. The temperature is not limited to increasing the reaction speed and the type of reactions may be affected, as well. The brownish to black color created in the maillard reaction is related to the formation of melanoyidins, which are compounds with high molecular weight. In order to form this colored materials, two possible mechanisms are considered including the formation of melanoyidins derived from the accumulation and polymerization of non-saturated multi-carbonate compounds produced during the maillard reaction and the polymerization of the furan compounds formed in this reaction. These reactions are actually carried out between the amine agent (-NH_2) and the amino acid and protein, or between the protein and the aldehyde or ketone agent of the sugars. Such reactions occur as a result of high storage or heating of food stuff, or when active water is low. The protein molecules are made of amino acids linked by a peptide bond to each other, and they can not interact in a normal state because they are connected to each other (Goyal *et al.,* 2007; Ahmadi Chenarbon *et al.,* 2012). However, heat creates a gap in the peptide bond site and releases the amine group and puts it alongside the carbonyl agent to carry out this reaction. On the other hand, a new form of pigments is created through some changes such as the dehydration of sugars or the tearing the chains between them and the formation of dicarbonyl compounds. In addition, the change in pigments can be related to the effect of heat on heat-sensitive compounds such as carbohydrates, proteins and vitamins, which result in the color variation during the drying process. On the other hand, the enhancement of air velocity decreases the intensity of the color changes due to the faster drying of the product and the lower effect of heat on the product. Further, the results indicated that ΔE index enhanced with increasing bed depth because the air enters into the product mass from the below of bed and transfers the heat during the product drying. In this case, the relative moisture of the drying air raises and the temperature decreases and this process occurs for all layers of product to dry every layer and reaches an equilibrium state with drying air. Therefore, the enhancement of depth prolongs the drying procedure with more thermal stress, leading to more change of color (Albanese *et al.,* 2013; Minaei *et al.,* 2014).

Conclusion

The current study examined the effect of temperature, hot air velocity and bed depth on some grapefruit properties during drying process. Based on the results, the best drying time was calculated 73 min, at 65 °C, hot air velocity of 2 ms^{-1} and bed depth of 1cm. Among the mathematical models investigated, the page model satisfactorily described the drying behavior of grapefruit slices. In addition, the maximum amount of the effective moisture diffusivity coefficient was measured 7.44×10^{-8} m^2s^{-1} and the minimum amount of activation energy was 16.09 $kJ.mol^{-1}$, at 65 °C, hot air velocity of 2 ms^{-1} and bed depth of 1cm. In the same vein, the maximum amount of vitamin C was 32.3 $mg(100g)^{-1}$ and the minimum amount of change color was obtained 23.76 at 55° and 45°C, respectively, hot air velocity of 2 ms^{-1} and bed depth of 1cm. As the maintenance of vitamin C in the dried product is very important, C7 treatment (drying at 55 °C, air velocity of 2 ms^{-1} and bed depth of 1cm) was selected as the best treatment.

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