Original Article
Journal of Biosystems Engineering
J. of Biosystems Eng. 42(4):314-322. (2017. 12)
https://doi.org/10.5307/JBE.2017.42.4.314
eISSN : 2234-1862
pISSN : 1738-1266

Determination of Hot Air Drying Characteristics of Squash (Cucurbita spp.) Slices

Soon-jung Hong[1], Dong Young Lee[2], Jeong Gil Park[2], Changyeun Mo[3], Seung Hyun Lee[2]*

[1]Smart Farm Education Team, Rural Human Resource Development Center, 420 Nongsaengmyeong-ro, Wansan-Gu, Jeonju-si, Jeollabuk-do, 54874, Korea
[2]Department of Biosystems Machinery Engineering, College of Agricultural and Life Science, Chungnam National University, 99 Daehak-ro, Yuseong-gu, Daejeon 34134, Korea
[3]National Institute of Agricultural Sciences, Rural Development Administration, 310 Nonsaengmyeong-ro, Wansan-gu, Jeonju-si, Jeollabuk-do 54875, Korea

Received: October 30th, 2017; Revised: November 14th, 2017; Accepted: November 15th, 2017

Abstract

Purpose: This study was conducted to investigate the hot air drying characteristics of squash slices depending on the drying conditions (input air velocity, input air temperature, and sample thickness). **Methods:** The developed drying system was equipped with a controllable air blower and electric finned heater, drying chamber, and ventilation fan. Squash (summer squash called Korean zucchini) samples were cut into slices of two different thicknesses (5 and 10 mm). These were then dried at two different input air temperatures (60 and 70 °C) and air velocities (5 and 7 m/s). Six well-known drying models were tested to describe the experimental drying data. A non-linear regression analysis was applied to determine model constants and statistical indices such as the coefficient of determination (R^2), reduced chi-square (χ^2), and root mean square error (RMSE). In addition, the effective moisture diffusivity (D_{eff}) was estimated based on the curve of ln(MR) versus drying time. **Results:** The results clearly showed that drying time decreased with an increase in input air temperature. Slice thickness also affected the drying time. Air velocity had a greater influence on drying time at 70°C than at 60°C for both thicknesses. All drying models accurately described the drying curve of squash slices regardless of slice thickness and drying conditions; the Modified Henderson and Pabis model had the best performance with the highest R2 and the lowest RMSE values. The effective moisture diffusivity (D_{eff}) changes, obtained from Fick's diffusion method, were between 1.67×10^{-10} and 7.01×10^{-10} m^2/s. The moisture diffusivity was increased with an increase in input air temperature, velocity, and thickness. **Conclusions:** The drying time of squash slices varied depending on input temperature, velocity, and thickness of slices. The further study is necessary to figure out optimal drying condition for squash slices with retaining its original quality.

Keywords: Drying models, Effective moisture diffusivity, Hot air drying, Squash (summer squash)

Introduction

Farmers commonly produce value-added products using surplus agricultural products. Harvested agricultural products go through continuous physiological changes due to respiration and the shelf lives of some agricultural products are quite limited. Controlled atmosphere (CA) and modified atmosphere (MA) storage facilities can control environment conditions such as the concentrations of oxygen, carbon dioxide, and nitrogen in order to extend shelf life; however, these require high energy consumption and maintenance costs. Freezing and drying methods have also been widely used to preserve agricultural products. Drying, one of the oldest and simplest preservation methods for food and agricultural products, removes the moisture in these products by

---

***Corresponding author:** Seung Hyun Lee
Tel: +82-42-861-6718; **Fax:** +82-42-823-6246
E-mail: seunglee2@cnu.ac.kr

evaporation (Ozkan et al., 2007). Drying can guarantee a longer shelf life and remarkable volume reduction. Therefore, dried agricultural products, which also provide nutritional and health benefits with low calories, have gained interest from consumers.

The drying process involves simultaneous heat and mass (moisture) transfer between heated media and agricultural products. At the beginning of the drying process, the mass (moisture) is initially transferred from the surface of the material and later gradually from the inside of the material to the environment. Therefore, it is essential to determine the drying parameters that affect drying time and rate as well as the quality of the final product (Kaya et al., 2008). Recently, hybrid combination drying methods such as simultaneous microwave/infrared and hot air/vacuum drying have been developed to improve product quality by shortening the drying time. For example, when microwaves and hot air are properly combined, the pumping action of microwave energy can efficiently remove free water from inside the product while hot air removes it near the surface (Andrés et al., 2004).

Convective air drying has also been commonly applied for commercial-scale drying of agricultural products. In this method, products are dried by passing hot air over their surface, so that the drying rate depends on the temperature and velocity of hot air and the moisture content of the product. It is essential to apply the appropriate air temperature for a given product because excessive heat during drying often leads to quality deterioration in the final product. For example, many researchers have studied the drying characteristics of various fruits (such as sweet cherries, apples, and peaches), determining that increasing air temperature and drying speed play an important role in lowering the quality index (color) value while reducing drying time (Doymaz and Osman, 2011; Zlatanović et al., 2013; Zhu and Shen, 2014). The drying time of pumpkin slices under convective air drying was also significantly affected by higher air temperatures at a constant air velocity (Doymaz, 2007). The dried squash slices have been widely used in Korea because it has a unique flavor, texture, and a large number of vitamins (Keum and Rhim, 1994). Recently, the demand of high quality dried agricultural product from the consumer was consistently increased. Accordingly, several companies have produced and distributed the high quality dried squash slices. However, there was a dearth of research regarding optimized drying mechanism for squash. Therefore, this study was conducted 1) to investigate the hot air drying characteristics of sliced squash samples under various conditions and 2) to determine a suitable model for describing the drying characteristics of squash slices and the effective moisture diffusivity under different drying conditions.

Materials and Methods

Sample preparation

The squash called Korean zucchini, is summer squash belonging to the species cucurbita moschata. Squash purchased from a local market were kept at room temperature prior to use. Each squash was washed with tap water and the samples cut manually into slices of two different thicknesses (5 and 10 mm, 49.64 ± 1.75 mm diameter)and using a sharp knife. The samples were dried at 105°C for 24 h in a convection dryer in order to determine the initial moisture content (AOAC, 1990), which was 11.50 ± 1.56 kg water per kg dry matter (dry basis).

Design of experimental equipment

Hot air drying equipment was designed and fabricated as shown in Figure 1, consisting of a drying chamber, electric finned heater, air blower fan, and a proportional-integrative-derivative (PID) controller. A modified heating cabinet (HD-W33, Habdong Precision Co., Ltd., Korea) was used as the drying chamber (W×H×D = 46 × 36 × 43 cm), which was not insulated. Hot air generated from the heater and fan was supplied to the bottom of the drying chamber through a circular duct (D×H = 6.5×10 cm). The input air temperature and velocity were managed by the PID controller (TC300P, Misung Scientific Co. Ltd., Korea) and a variable transformer (Han Chang Transformer Co., Ltd., Busan, Korea), respectively. Input air temperature from the output of the circular duct was measured using a thermocouple (T-type, Omega Engineering Inc., Stamford, CT, USA) connected to the PID controller. Temperature values inside the drying chamber were measured using 17 thermocouples (T-type, Omega Engineering Inc., Stamford, CT, USA) installed at different locations and recorded by a data logger (Agilent 34970A, Agilent Technologies, Santa Clara, CA, USA). A hygro-anemometer (HHC261, OMEGA Engineering, Inc., USA) with a resolution of 0.1 m/s was used to determine the hot air velocity. A small centrifugal fan was installed on the bottom center of the drying chamber's rear to control moisture condensation in the dryer.

Drying experiments

Squash slices were spread in thin layers on a circular mesh tray made of Teflon thread and stainless steel. The samples were dried at air temperatures of 60 and 70 °C with an air velocity of 5 and 7 m/s. The inside drying chamber was preheated until the target air temperature was reached. As the drying process progressed, the weight value of the slice samples was measured twice at an interval of 20 min at the initial stage; afterward the interval was increased to 1 h. When the moisture content of slice samples reached around 10% (wet basis), the drying experiment was stopped.

Mathematical modeling of hot air drying curves

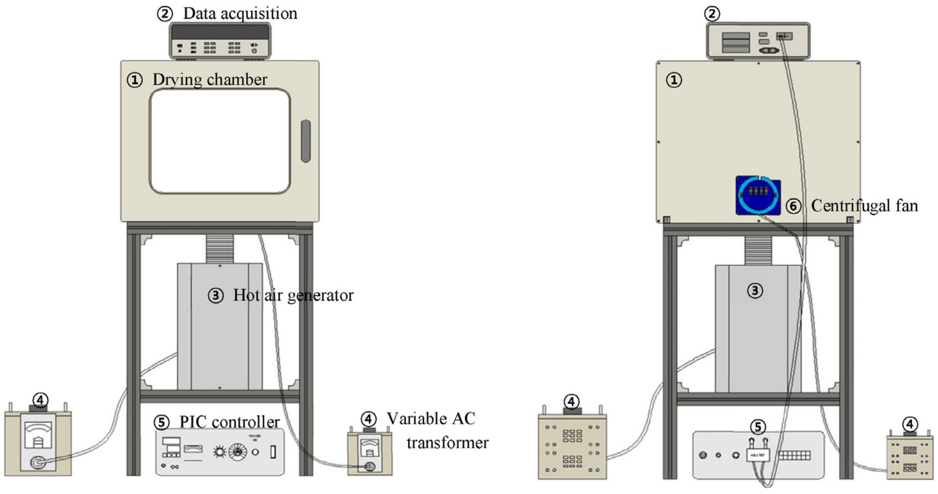
The drying rate and moisture ratio (MR) of the squash slices were calculated using following equations:

$$\text{Moisture tatio (MR)} = \frac{M - M_e}{M_0 - M_e} \quad (1)$$

$$\text{Drying rate} = \frac{M_{t+dt} - M_t}{dt} \quad (2)$$

where M, M_0, and M_e are the moisture content at any time, initial moisture content, and equilibrium moisture contents (kg water per kg dry base), respectively. M_t and M_{t+dt} are the moisture content at t and $t+dt$ (kg water per kg dry base), respectively, where t is time (min).

Six drying models that have been widely used for fitting of experimental hot air drying characteristics (summarized in Table 1) were applied to select the model that best describes the drying curves of squash slices. Non-linear



(a) (b)

Figure 1. Schematic diagrams of the hot air drying equipment: (a) front view, (b) rear view.

Table 1. Drying models used for prediction of sliced squash drying behavior

Drying model	Equation	Reference
Newton	$MR=\exp(-kt)$	O'Callaghan et al. (1971)
Page	$MR=\exp(-kt^{n)}$	Page (1949)
Henderson and Pabis	$MR=a\exp(-kt)$	Henderson and Pabis (1961)
Logarithmic	$MR=a\exp(-kt)+c$	Yagcioglu et al. (1999)
Modified handerson and pabis	$MR=a\exp(-kt)+b\exp(-gt)+c\exp(-ht)$	Karathanos (1999)
Two-Term	$MR=a\exp(-kt)+b\exp(-k_0 t)$	Madamba et al. (1996)

regression analysis was performed to estimate model parameters using SPSS 24.0 software (SPSS Inc, Chicago, IL, USA). Model comparative indices such as determination coefficient (R^2), root mean square error (RMSE), and chi-square (χ^2) were determined to evaluate the goodness of fit of the experimental data for the different models. Chi-square (χ^2) can be often defined as the standard deviation (Midilli et al., 2002). The best model for describing the drying curves should have the highest R^2 and lowest χ^2 values (Lee and Kim, 2009). The χ^2 and RMSE were calculated as follows:

$$\chi^2 = \frac{\Sigma_{i=1}^{N}(MR_{pre,i} - MR_{\exp,i})^2}{N - z} \tag{3}$$

$$RMSE = \left[\frac{1}{N}\Sigma_{i=1}^{N}(MR_{pre,i} - MR_{\exp,i})^2\right]^{\frac{1}{2}} \tag{4}$$

where $MR_{exp,i}$ is the i^{th} experimental moisture ratio, $MR_{pre,i}$ is the i^{th} predicted moisture ratio, N is the number of observation, and z is the number of drying constants.

Moisture diffusivity

Fick's diffusion equation for rectangular (slab) shapes was used to determine the effective moisture diffusivity (Chayjan et al., 2013). Fick's second law can be used to determine the moisture ratio and effective moisture diffusivity for an infinite slab (Mirzaee et al., 2009):

$$\begin{aligned} MR &= \frac{M - M_e}{M_0 - M_e} \\ &= \frac{8}{\pi^2}\sum_{n=1}^{\infty}\frac{1}{(2n+1)^2}exp\left(-\frac{D_{eff}(2n-1)^2\pi^2 t}{4L^2}\right) \end{aligned} \tag{5}$$

where n=1, 2, 3, ⋯ is the number of terms taken into consideration, D_{eff} is the effective moisture diffusivity (m^2/s), t is the drying time (s), and L is the thickness of the slice (m).

For a long drying time, n in Eq. (5) can be considered as 1; hence, Eq. (5) can be simplified as a logarithmic form (Wang et al., 2007):

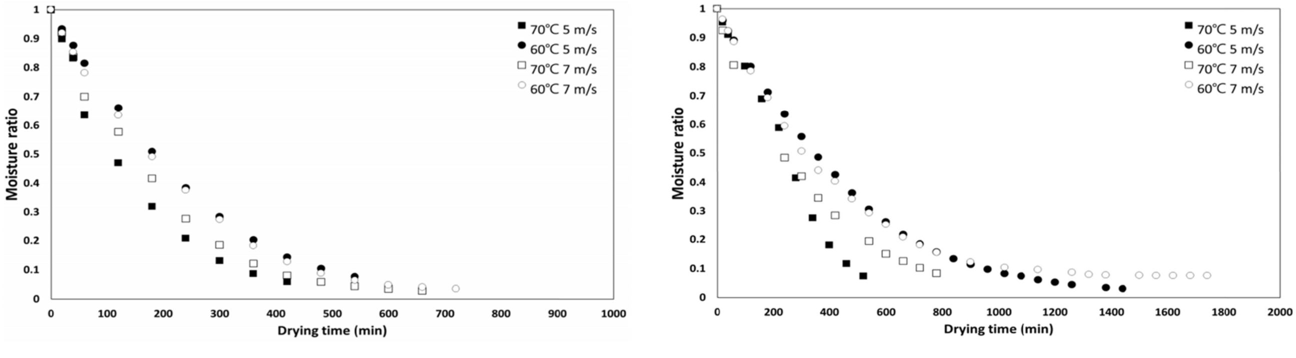
$$\ln MR = \ln\frac{8}{\pi^2} - \frac{D_{eff}\pi^2 t}{4L^2} \tag{6}$$

The effective moisture diffusivity can be determined by the slope of a straight line obtained by plotting experimental ln(MR) against drying time (Akgun and Doymaz, 2005; Lee and Kim, 2009).

Results and Discussion

Hot air drying characteristics of squash slices

Figure 2 shows the drying curves of squash slices under different conditions. The air temperature and slice thickness significantly affected the drying time at the same air velocity. As expected, the input air temperature had a pronounced effect on the drying time of the squash slices at both of thickness. Higher air velocity lengthened the drying time of 10 mm squash slices at both of 60 and 70°C input temperature. However, in the drying of 5mm squash slices, the input air velocity does not significantly affect drying time. These results were in agreement with research regarding the drying of barley and onions under a combination of infrared and hot air drying methods (Afzal et al., 1999; Kumar et al., 2006). It may be that a higher air velocity first removed moisture on the slices'



(a) (b)

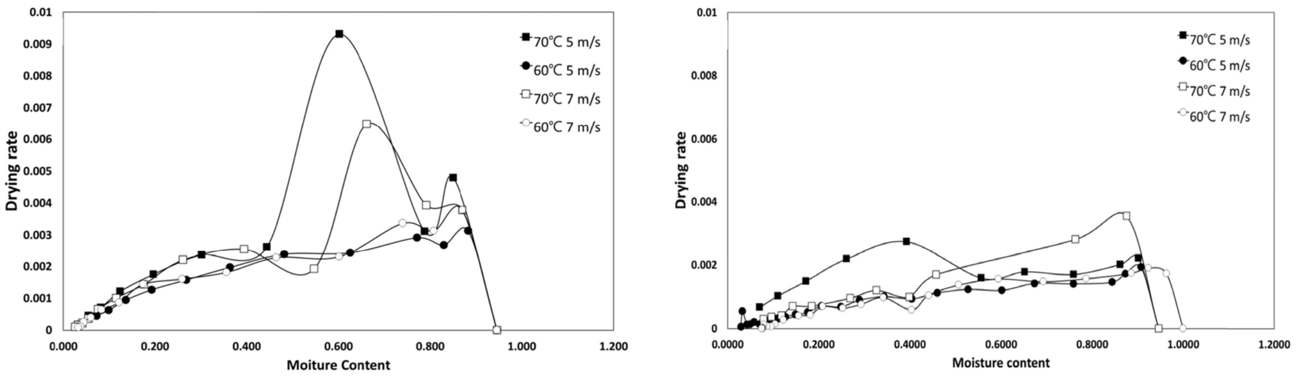
Figure 2. Drying curves of squash slices: (a) 5 mm and (b) 10 mm in thickness.

surface, which became a thermal barrier (known as case hardening) that prevented further removal of moisture inside the slice. As shown in Figure 3, a constant drying rate was not observed under all drying conditions and moisture was rapidly removed at the initial stage of drying. The drying rate clearly increased with an increase in air temperature and the drying rate of thin slices was higher than that for thicker slices.

When 10 mm slices were dried at different air temperatures and constant velocities, non-uniform temperature distributions in the drying chamber were observed (Table 2). The average temperature in this chamber at 60 and 70 °C input air temperature was 45.85 and 54.75 °C, respectively. Since the drying chamber was not insulated, the temperature near the door was lower than other locations. However, the slices' drying rate increased with an increase in input air temperature even under a non-uniform temperature distribution inside the chamber.

Evaluation of drying models

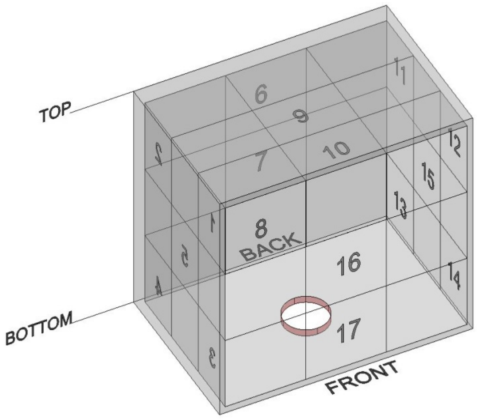
Six drying models were applied to describe the drying curve obtained from these experiments; model constants and *t* statistical indices such as coefficient of deter-



(a) (b)

Figure 3. Drying rate curves of squash slices: (a) 5 mm and (b) 10 mm in thickness.

Table 2. Temperature distribution in the drying chamber at a steady state (slice thickness: 10 mm, air velocity: 7 m/s)

Thermocouple location in hot air dryer	No.	Input air temperature	
		60°C	70°C
	1	46.42 ± 0.86	55.05 ± 0.41
	2	47.52 ± 1.04	57.69 ± 0.49
	3	42.91 ± 0.62	49.98 ± 0.65
	4	44.45 ± 0.52	52.85 ± 0.51
	5	43.50 ± 1.80	54.94 ± 0.78
	6	50.28 ± 0.90	58.68 ± 0.60
	7	49.97 ± 0.32	60.14 ± 0.59
	8	42.47 ± 0.29	56.63 ± 0.72
	9	52.84 ± 0.78	62.17 ± 0.49
	10	48.67 ± 0.34	57.74 ± 0.48
	11	49.36 ± 1.26	56.14 ± 2.46
	12	49.09 ± 0.82	57.73 ± 0.52
	13	47.79 ± 0.53	54.25 ± 0.50
	14	41.55 ± 0.50	47.25 ± 0.65
	15	47.75 ± 0.59	58.58 ± 0.46
	16	38.20 ± 3.65	47.36 ± 2.87
	17	36.78 ± 1.35	43.69 ± 1.50

mination (R^2), reduced chi-square (χ^2), and root mean square error (RMSE) are summarized in Tables 3 and 4. Regardless of input air temperature, air velocity, and slice thickness, all R^2 values of the applied models were greater than 0.99 and so all models were suitable for describing the experimental data. In addition, almost all RMSEs of the applied models were lower than 0.05, also suggesting that all models were appropriate for describing the experimental data. Although the Modified Henderson and Pabis model was the best based on R^2, χ^2 and RMSE, the Newton model is more convenient because it has a simple form and one parameter (Rhim and Lee, 2011).

Table 3. The applied drying model constants and statistical indices for 5 mm squash slices

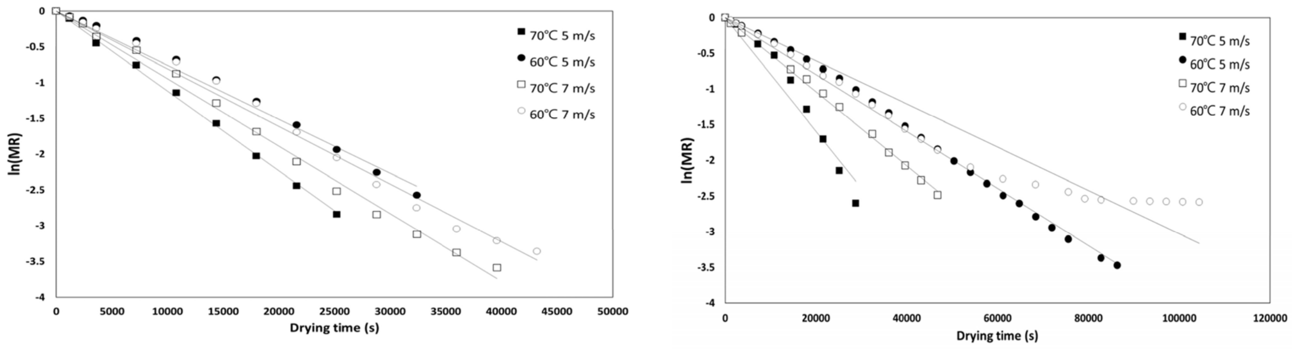
Name of model	Air speed (m/s)	5		7	
	Temperature (°C)	60	70	60	70
Newton	*k*	0.0041	0.0065	0.0044	0.0053
	R^2	0.9926	0.9944	0.9950	0.9954
	RMSE	0.0298	0.0267	0.0251	0.0244
	χ^2	0.0009	0.0007	0.0006	0.0006
Page	*k*	0.0015	0.0049	0.0021	0.0033
	n	1.1761	1.0542	1.1271	1.0879
	R^2	0.9993	0.9952	0.9983	0.9971
	RMSE	0.0094	0.0262	0.0154	0.0204
	χ^2	0.0001	0.0007	0.0002	0.0004
Henderson	*a*	1.0316	1.0179	1.0206	1.0187
	k	0.0043	0.0066	0.5762	0.0054
	R^2	0.9946	0.9950	0.9957	0.9959
	RMSE	0.0266	0.0268	0.0244	0.0240
	χ^2	0.0007	0.0007	0.0006	0.0006
Logarithmic	*a*	1.1562	1.0316	1.0636	1.0389
	k	0.0032	0.0063	0.0039	0.0050
	c	-0.1446	-0.0179	-0.0566	-0.0283
	R^2	0.9989	0.9952	0.9979	0.9967
	RMSE	0.0127	0.0282	0.0178	0.0225
	χ^2	0.0002	0.0008	0.0003	0.0005
Two - Term	*a*	12.6326	4.5419	17.8057	17.3552
	k	0.0022	0.0053	0.0027	0.0037
	b	-11.6225	-3.5292	-16.8016	-16.3478
	k_0	0.0020	0.0049	0.0027	0.0037
	R^2	0.9991	0.9952	0.9983	0.9970
	RMSE	0.0121	0.0304	0.0165	0.0225
	χ^2	0.0001	0.0009	0.0003	0.0005
Modified Henderson and Pabis	*a*	13.7780	1.0149	26.2933	16.4573
	k	0.0005	0.0064	0.0010	0.0019
	b	-20.2597	-1.0782	17.5116	11.2582
	g	0.0000	-0.0109	0.0003	0.0011
	c	7.4820	1.0766	-42.8137	-26.7180
	h	0.0005	0.0109	0.0007	0.0015
	R^2	0.9999	0.9952	0.9996	0.9977
	RMSE	0.0046	0.0371	0.0086	0.0219
	χ^2	0.0000	0.0014	0.0001	0.0005

Table 4. The applied drying model constants and statistical indices for 10 mm squash slices

Name of model	Air speed (m/s)	5		7	
	Temperature (°C)	60	70	60	70
Newton	*k*	0.0022	0.0034	0.0038	0.0031
	R^2	0.9942	0.9492	0.9978	0.9982
	RMSE	0.0255	0.0793	0.0158	0.0139
	x^2	0.0007	0.0063	0.0003	0.0002
Page	*k*	0.0008	0.0001	0.0026	0.0031
	n	1.1610	1.6116	0.9736	0.9973
	R^2	0.9993	0.9929	0.9938	0.9982
	RMSE	0.0001	0.0001	0.0001	0.0001
	χ^2	0.0000	0.0000	0.0000	0.0000
Henderson	*a*	1.0292	1.0602	1.0058	0.9895
	k	0.0023	0.0036	0.0022	0.0031
	R^2	0.9954	0.9570	0.9937	0.9985
	RMSE	0.0232	0.0769	0.0260	0.0136
	χ^2	0.0005	0.0059	0.0007	0.0002
Logarithmic	*a*	1.0746	2.6601	0.9762	1.0267
	k	0.0020	0.0009	0.0025	0.0028
	c	-0.0608	-1.6490	0.0463	-0.0437
	R^2	0.9981	0.9926	0.9978	0.9992
	RMSE	0.0151	0.0340	0.0158	0.0106
	χ^2	0.0002	0.0012	0.0003	0.0001
Two-Term	*a*	17.1784	13.0553	1.0082	0.9891
	k	0.0014	0.0006	0.0024	0.0029
	b	-16.1676	-12.0440	0.0123	-0.0051
	k_0	0.0013	0.0004	-0.0008	-0.0023
	R^2	0.9986	0.9926	0.9984	0.9992
	RMSE	0.0133	0.0361	0.0136	0.0110
	χ^2	0.0002	0.0013	0.0002	0.0001
Modified Henderson and Pabis	*a*	2.8286	3.0010	1.2446	0.0675
	k	0.0010	0.0008	0.0019	0.0304
	b	0.7168	-0.9947	-0.9131	-8.5464
	g	-0.0002	0.0001	0.0001	0.0017
	c	-2.5444	-0.9947	0.6793	9.4797
	h	0.0003	0.0001	-0.0001	0.0018
	R^2	0.9996	0.9926	0.9993	0.9998
	RMSE	0.0075	0.0429	0.0095	0.0062
	χ^2	0.0001	0.0018	0.0001	0.0000

Determination of effective moisture diffusivity

In order to determine the effective moisture diffusivity using the slope method, a diagram should be obtained of the logarithm of experimental moisture ratio (ln(MR)) versus drying time at different drying conditions; the slope of this graph should then be checked as shown in Figure 4. When ln(MR) was plotted against drying time, linearity could be achieved. Equation 6 can then be rewritten as following (Akgun and Doymaz, 2005):



(a) (b)

Figure 4. Diagram of ln (MR) against drying time for (a) 5 mm and (b) 10 mm squash slices.

Table 5. Estimated effective moisture diffusivity (D_{eff}) obtained under different drying conditions of squash slices

		5 mm thickness		
Air velocity (m/s)	Temperature (°C)	Slope	D_{eff} (m^2/s)	R^2
5	60	-6.61×10^{-5}	1.67×10^{-10}	0.9468
5	70	-9.97×10^{-5}	2.53×10^{-10}	0.9729
7	60	-7.34×10^{-5}	1.86×10^{-10}	0.9719
7	70	-8.67×10^{-5}	2.20×10^{-10}	0.9809
		10 mm thickness		
5	60	-3.62×10^{-5}	3.67×10^{-10}	0.9726
5	70	-6.91×10^{-5}	7.01×10^{-10}	0.8956
7	60	-2.74×10^{-5}	2.77×10^{-10}	0.9377
7	70	-4.58×10^{-5}	4.64×10^{-10}	0.9737

$$\text{Slope}=\frac{D_{eff}\pi^2}{4L^2} \qquad (7)$$

The effective moisture diffusivity was estimated based on the linearity (Table 5). The estimated effective diffusivity (D_{eff}) ranged from 1.67×10^{-10} to 7.19×10^{-10} m^2/s. At the same drying conditions, D_{eff} clearly increased with an increase in slice thickness. In addition, at the same slice thickness and air velocity, higher D_{eff} was obtained from higher temperatures. D_{eff} was thus significantly dependent on drying conditions and slice thickness.

Conclusion

The hot air drying characteristics of squash slices were investigated in this study. The drying time varied depending on the input air temperature, air velocity, and slice thickness. An increase in input air temperature could significantly reduce drying time. In addition, for both input temperatures (60 and 70 °C), the drying time at 10 mm squash slices was increased by a higher air velocity, whereas this effect was far less pronounced at 5 mm thickness. Under all drying conditions, a constant drying rate was not found and the highest drying rate was obtained during the initial drying stage. The tested six models were all suitable for clearly describing the drying curves of squash slices, with coefficients of determination (R^2) greater than 0.99; the best model was the Modified Henderson and Pabis. The effective moisture diffusivity (D_{eff}) estimated by the curve of ln (MR) versus drying time ranged between 1.67×10^{-10} to 7.01×10^{-10} m^2/s. The D_{eff} values also varied depending on drying condition.

Conflict of Interest

The authors have no conflicting financial or other interests.

Acknowledgement

This work was carried out with the support of the "Cooperative Research Program for Agriculture Science and Technology Development (Project No. PJ01224701)" Rural Development Administration, Republic of Korea.

References

Afzal, T. M., T. Abe and Y. Hikida. 1999. Energy and quality aspects during combined FIR-convection drying of barley. Journal of food engineering 42(4):177-182.

Andrés, A., C. Bilbao and P. Fito. 2004. Drying kinetics of apple cylinders under combined hot air-microwave dehydration. Journal of Food Engineering 63(1):71-78.

Akgun, N. A. and I. Doymaz. 2005. Modelling of olive cake thin-layer drying process. Journal of food Engineering 68(4):455-461.

AOAC. 1990. Official Method of Analysis. Association of Official Analytical Chemists (No. 934. 06), Arlington, VA.

Chayjan, R. A., K. Salari, Q. Abedi and A. A., Sabziparvar. 2013. Modeling moisture diffusivity, activation energy and specific energy consumption of squash seeds in a semi fluidized and fluidized bed drying. Journal of food science and technology 50(4):667-677.

Doymaz, I. 2007. The kinetics of forced convective air-drying of pumpkin slices. Journal of food engineering 79(1):243-248.

Doymaz, İ. and I. Osman. 2011. Drying characteristics of sweet cherry. Food and Bioproducts Processing 89(1):31-38.

Henderson, S. M. and S. Pabis. 1961. Grain drying theory. II. Temperature effects on drying coefficients. Journal of Agricultural Engineering Research 6:169-174.

Karathanos, V. T. 1999. Determination of water content of dried fruits by drying kinetics. Journal of Food Engineering 39:337-344.

Kaya, A., O. Aydın and I. Dincer. 2008. Experimental and numerical investigation of heat and mass transfer during drying of Hayward kiwi fruits (*Actinidia Deliciosa Planch*). Journal of Food Engineering 88(3): 323-330.

Keum T. H. and J. W. Rhim. 1994. Effect of Various Pretreatments and Drying Methods on the Quality of Dried Vegetables. Korean journal of food science and technology 26:805-813.

Kumar, D. P., H. H. U. Hebbar and M. N. Ramesh. 2006. Suitability of thin layer models for infrared-hot air-drying of onion slices. LWT-Food Science and Technology 39(6):700-705.

Lee, J. H. and H. J., Kim. 2009. Vacuum drying kinetics of Asian white radish (*Raphanus sativus L.*) slices. LWT-Food Science and Technology 42(1):180-186.

Madamba, P. S., R. H. Driscoll and K. A. Buckle. 1996. The thin-layer drying characteristics of garlic slices. Journal of Food Engineering, 29, 75-97.

Midilli, A., H. Kucuk and Z. Yapar. 2002. A new model for single-layer drying. Drying technology 20(7):1503-1513.

Mirzaee, E., S. Rafiee, A. Keyhani and Z. Emam-Djomeh. 2009. Determining of moisture diffusivity and activation energy in drying of apricots. Research in Agricultural Engineering 55(3):114-120.

O'Callaghan, J. R., D. J. Menzies and P. H. Bailey. 1971. Digital simulation of agricultural dryer performance. Journal of Agricultural Engineering Research 16:223-244.

Ozkan, I. A., B. Akbudak and N. Akbudak. 2007. Microwave drying characteristics of spinach. Journal of Food Engineering 78(2):577-583.

Page, G. 1949. Factors influencing the maximum rates of air-drying shelled corn in thin layer. M.S. Thesis. Department of Mechanical Engineering, Purdue University, West Lafayette, IN, USA.

Rhim, J. W. and Lee, J. H. 2011. Drying kinetics of whole and sliced shiitake mushrooms (Lentinus edodes). Food Science and Biotechnology 20(2):419-427.

Wang, Z., J. Sun, X. Liao, F. Chen, G. Zhao, J. Wu and X. Hu. 2007. Mathematical modeling on hot air drying of thin layer apple pomace. Food Research International 40(1):39-46.

Yagcioglu, A., A. Degirmencioglu and F. Cagatay. 1999. Drying characteristic of laurel leaves under different conditions. In A. Bascetincelik (Ed.), Proceedings of the 7th international congress on agricultural mechanization and energy, 26-27 May, Adana, Turkey (pp. 565-569). Faculty of Agriculture, Çukurova University.

Zhu, A. and X. Shen. 2014. The model and mass transfer characteristics of convection drying of peach slices. International Journal of Heat and Mass Transfer 72:345-351.

Zlatanović, I., M. Komatina and D. Antonijević. 2013. Low-temperature convective drying of apple cubes. Applied Thermal Engineering 53(1):114-123.