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Moisture Content Modeling of Sliced Kiwifruit (cv. *Hayward*) During Drying

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Abstract: Drying behavior of kiwifruit slice was studied at 40, 50, 60, 70 and 80°C and at a constant air velocity of 1.5 m/s for constant sample thickness of 4 mm in a thin layer dryer. Sample weight, temperature and drying air velocity were measured during drying and drying curves were obtained for each experimental data. The curves were fitted to twelve different semi-theoretical and/or empirical thin-layer drying models to estimate a suitable model for drying of kiwifruit. Coefficients were evaluated by non-linear regression analysis. The models were compared based on their coefficient of determination (EF), root mean square error (RMSE) and reduced chi-square (x^2). Midilli model had the highest value of EF (0.999319), the lowest RMSE (0.032536) and x^2 (0.001119). The Midilli model was found to satisfactorily describe the drying behavior of kiwifruit.

Key words: Thin-layer drying, kiwifruit, modeling, midilli model

Introduction

Kiwifruit *(Actinidia deliciosa)* is a commonly eaten fruit in certain countries. Although anecdotal reports and dietary advice have suggested the use of kiwifruit as a laxative, no controlled human trial data are available. The cultivation of kiwifruit trees in orchards of northern Iran, with more than 3500 hectares and 87000 tones produce, making this country one of the most important producers of kiwifruit in the world. Iran has exported more than 48000 tones to different countries in 2005 (FAO, 2005). Drying of food is a complex operation, because of difficulties in mathematical description of such phenomena as simultaneous (and often coupled and multiphase) transport of heat, mass and momentum in solid media. Transport processes are mostly in the unsteady state. Preserving the delicate characteristics of raw foods requires proper design and skillful operation of the dehydrator which demands a good understanding of the principles of dehydration.

Although many experimental works are conducted on drying of different fruits (e.g., Bala *et al.*, 2003; Rafiee and Kashaninejad, 2005; Doymaz, 2006; Sharifi *et al.*, 2006; Wang et al., 2007; Erenturk and Erenturk, 2007; Scala and Crapiste, 2008; Prachayawarakorn *et al.*, 2008), there are a few studies on the drying kinetics of kiwi fruits: Maskan (2001) studied to comparison of the microwave, hot air and hot air-microwave drying methods for the processing of kiwi fruits in respect to drying, shrinkage and rehydration characteristics obtained by the three drying techniques. Chen *et al.* (2001) established the drying kinetics parameters through the experiments performed on pulped kiwifruit flesh spread onto a hallow metal tray (forming a layer) to simulate the process of making fruit leather. Simal *et al.* (2005a) studied to evaluate alternate empirical or simple phenomeno-logical models reported in literature to simulate the drying curves of kiwifruits and proposed a simple model to accurately simulate the drying kinetics of kiwis with different geometries and at different drying air temperatures. Simal *et al.* (2005b) also evaluated the behavior of kiwifruits at different ripening stages during drying with hot air and on the other to propose a diffusional model to accurately simulate the drying kinetics of kiwis at different maturity stages using different air temperatures during dehydration. Further, the quality of the dried products was also assessed.

The aim of this study was to develop a mathematical model for predicting the thin layer drying kinetics of convection drying of kiwifruits at different drying air temperature and velocity conditions and was compared time in the different conditions of drying and estimate the constants of selected model equations as well as.

Materials and Methods

Fresh kiwifruits (*Actinidia deliciosa*) of the cultivar *Hayward* were purchased from a local market. The whole samples were stored at 4 ± 0:5°C before they were used in experiments in order to slow down the respiration, physiological and chemical changes (Oconnor-Shaw *et al.*, 1994). To determine the initial moisture content, the drying process was continued until the drying rate tended to become zero. After that the samples were placed in an oven at 65°C for 24 h (Mirzaee Moghadam *et al.*, 2007) to find the moisture content according to the following equation:

$$M = \frac{W_w - W_d}{W_d} \qquad (1)$$

where M is the bergamot slice moisture content (d.b.), W_w is the wet weight and W_d the dried weight.

Table 1: Specifications of measurement instruments including their rated accuracy

Instrument	Model	Accuracy	Make
Digital balance	GF3000	±0.02g	A and D, Japan
T-sensor	LM35	±1°C	NSC, USA
RH-sensor	Capacitive	±3%	PHILIPS, UK
V-sensor	405-V1	±3%	TESTO, UK

The initial moisture content of kiwifruit was obtained as 4.24-4.83 (g water.g dry base^{-1}). The reproducibility of the initial moisture content measurements was within the range of ±5%.

The laboratory dryer and experiments: Drying experiments were performed in a laboratory dryer in the Department of Agricultural Machinery, Faculty of Biosystems Engineering, University of Tehran. The dryer is capable of providing any desired drying air temperature in the range of 40 to 80°C and constant air velocity at 1.0 m/s with high accuracy. Fig. 1 shows a schematic diagram of the dryer used for experimental work it consists of a fan, heaters, drying chamber and instruments for various measurements. The airflow rate was adjusted by the fan speed control. The heating system consisted of four 1000W electric heating elements (total of 4000W) placed inside the duct. The drying chamber temperature was adjusted by a microcontroller. Two drying trays were placed inside the drying chamber. For the measurements of temperatures, thermocouples were used with a manually digital thermometer (Testo 925, Germany) with reading accuracy of 0.1°C. A thermo hygrometer (Loutron HT-3005) was used to measure relative humidity levels at various locations of the system. The velocity of air passing through the system was measured by a hot wire anemometer (Testo, 405 V1, Germany). Specifications regarding the measurement instruments including their rated accuracy are summarized in Table 1.

Data analysis: The moisture content was expressed as a percent wet basis and then converted to g water per g dry matter. The experimental drying data for kiwifruit were fitted to the thin layer drying models in Table 2 by using SPSS version 13.0 software, nonlinear regression technique. For mathematical modeling, the thin layer drying equations in Table 2 were tested to select the best model for describing the drying curve of the kiwifruit. The modeling efficiency (EF), root mean square error (RMSE) and reduced chi-square (x^2) obtained for these equations were used to compare the relative goodness of fit of experimental data. These parameters can be calculated as follows:

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

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

$$EF = \frac{\sum_{i=1}^{N} (MC_{i,\exp} - MC_{i,\exp_{mean}})^2 - \sum_{i=1}^{N} (MC_{i,pre} - MC_{i,\exp})^2}{\sum_{i=1}^{N} (MC_{i,\exp} - MC_{i,\exp_{mean}})^2} \quad (4)$$

where $MC_{exp,i}$ is the ith experimental moisture content, $MC_{pre,i}$ is the ith predicted moisture content, N is the number of observations, n is the number of constants in the drying model and $MC_{expmean}$ is the mean value of experimental moisture content.

The best model describing the drying behaviour of kiwifruitwas chosen as the one with the highest coefficient of determination and the least mean relative percent error and the least root mean square error. In addition, reduced chi-square was used to determine the goodness of the fit. The lower values of the reduced chi-square, the better goodness of the fit.

Results and Discussion

Initial moisture content of kiwifruit was 4.24-4.83 g water.g dry base^{-1}. Moisture content of kiwifruits decreased steadily throughout the drying period.

The drying rate, DR, is expressed as the amount of the evaporated moisture over time. The drying rates of kiwifruit slices were calculated by using Eq. (5):

$$\text{Drying Rate} = \frac{M_{t+dt} - M_t}{dt} \quad (5)$$

where, M_t and M_{t+dt} are the moisture content at t and moisture content at $t + dt$ (kg moisture/kg dry matter), respectively, t is drying time (min).

Fig. 2 shows the drying rate versus the variations of drying rate with moisture content of the samples at temperatures of 40 - 80°C of drying air and velocity of 1.5 m/s, respectively.

As shown in Fig. 2, the average initial moisture content of around 4.6 kg water per kg dry matter was dried to the final moisture content of about 0.1 (d.b.) until no further changes in their mass were observed. During the experiments, the time to reach final moisture content of 0.1 (d.b.) for were found to be between 180 and 450 min. The decrease in the drying time could be due to the values of higher temperature and lower relative humidity obtained in dryer. Similar results have been reported by Bala *et al.* (2003) for pineapple and Prachayawarakorn *et al.* (2008) for banana.

The moisture content of kiwifruit slices at various drying air temperatures were fitted in twelve models and the results of statistical analysis. In seven cases (Table 3), the value of EF was greater than 0.99 indicating a good

Table 2: Mathematical models applied to drying curves

References	Model	Model name	Model no.
Westerman *et al.*, 1973	MC = exp(-kt)	Newton	1
Page, 1949	MC = exp(-kt^n)	Page	2
Overhults *et al.* (1973)	MC = exp[-(kt)^n]	Modified Page	3
Henderson and Pabis (1961)	MC = a exp(-kt)	Henderson and Pabis	4
Yaldiz and Ertekin, 2001	MC = a exp(-kt) + c	Logarithmic	5
Rahman *et al.*, 1998	MC = a exp(-k$_0$t) + b exp(-k$_1$t)	Two term	6
Yaldiz and Ertekin, 2001	MC = a exp(-kt)+(1-a)exp(-kat)	Exponentioal two term	7
Wang and Singh (1978)	MC = 1+at+bt^2	Wang and Sing	8
Yaldiz and Ertekin, 2001	MC = a exp(-kt)+(1-a)exp(-kbt)	Approximation of diffusion	9
Verma *et al.*, 1985	MC = a exp(-kt)+(1-a)exp(-gt)	Verma *et al.*	10
Karathanos, 1999	MC = a exp(-kt) + bexp(-gt) + cexp(-ht)	Modified Henderson and Pabis	11
Midilli *et al.* (2002)	MC = a exp(-kt^n)+bt	Midilli *et al.*	12

Table 3: Values of the drying constants and coefficients of different models determined through regression method for all temperature values

Model no.	Model name	X^2	RMSE	EF
1	Henderson and Pabis	0.015114	0.121713	0.991119
2	Logarithmic	0.009348	0.093667	0.994447
3	Two term	0.015114	0.121713	0.991119
4	Diffusion Approximation	0.015022	0.121347	0.991171
5	Verma *et al.*	0.015028	0.121373	0.991167
6	Modified Henderson and Pabis	0.015114	0.121713	0.991119
7	Midilli *et al.*	0.001119	0.032536	0.999319

Table 4: Values of the drying constant and coefficients of the Midilli et al. model determined through regression method for each of the temperature values

Temp. (°C)	a	K (min^{-1})	N	B (min^{-1})	x^2	RMSE	EF
40	4.664324	0.001585	1.304369	0.000072	0.001303	0.036098	0.999301
50	4.513277	0.003701	1.192239	-0.000112	0.000452	0.021249	0.999728
60	4.649987	0.002102	1.407114	0.000280	0.000707	0.026581	0.999637
70	4.652942	0.004529	1.325605	0.000355	0.001265	0.035559	0.999312
80	3.875297	0.003415	1.466243	0.000300	0.001866	0.043191	0.998616

Temp. (°C): Temperature (°C).

Table 5: Values of the drying constant and coefficients of the Logarithmic model determined through regression method for each of the temperature values

Temp.(°C)	a	K (min^{-1})	C	x^2	RMSE	EF
40	5.298381	0.007183	-0.22128	0.008012	0.089503	0.995702
50	5.018031	0.008808	-0.26140	0.002563	0.050618	0.998458
60	5.40799	0.012741	-0.23381	0.013346	0.115506	0.993146
70	5.268976	0.017526	-0.16875	0.009347	0.096662	0.994916
80	4.548636	0.022315	-0.14591	0.013473	0.116046	0.990012

Temp. (°C): Temperature (°C).

fit (Madamba *et al.*, 1996). The results show that, in all drying temperatures, highest values of EF (0.999319) and lowest values of x^2(0.001119) and RMSE (0.032536) could be obtainable with the Midilli drying model followed by Logarithmic model (Table 3). The average of RMSE (0.032536) of Midilli model was 0.34736 times as much as that (0.093667) of Logarithmic model. Therefore, Midilli model was most adequate in describing the hot air drying processes of kiwifruit slices. Togrul (2006) and Cihan *et al.* (2007) have reported similar results for air drying of carrot and rough rice, respectively. The least suitable models are the Henderson and Pabis and Modified Henderson and Pabis models.

It is clear that, in Midilli model, RMSE and chi-square values were very low and changed between 0.021249 - 0.043191 and 0.000452 - 0.001866, respectively. Modeling efficiency (EF) also ranged from 0.998616 and 0.999728. This model represented the experimental values satisfactorily. In Logarithmic model too, RMSE and chi-square values were very low (Table 3, 4). Fig. 3 shows the comparison between predicted values from Midilli model and experimental data for kiwifruit slices at the hot air drying within the given temperature range.

Conclusion: The drying behaviour of kiwifruit slices in a laboratory dryer was investigated at five different drying air temperatures. The time required to dry kiwifruit slices from an initial moisture content of 4.24-4.83 (d.b.) to the final moisture content of about 0.1 (d.b.) was 450, 340, 270, 210 and 180 min at 40, 50, 60, 70 and 80°C of

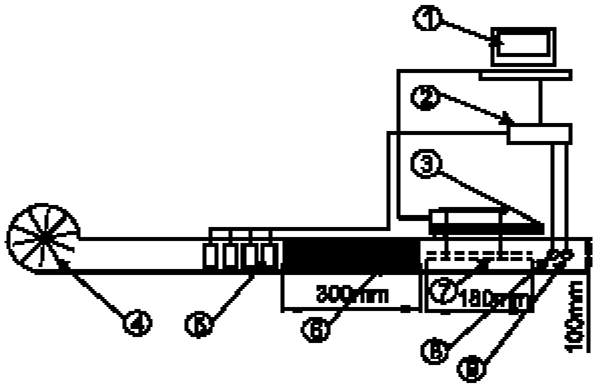

Fig. 1: Schematic diagram of the drying system for measurement of the thin - layer parameters of kiwifruit slices. 1. PC; 2. microcontroller; 3. digital balance; 4. fan; 5. heating elements; 6. duct and tunnel; 7. trays; 8. temperature sensor; 9. relative humidity sensor.

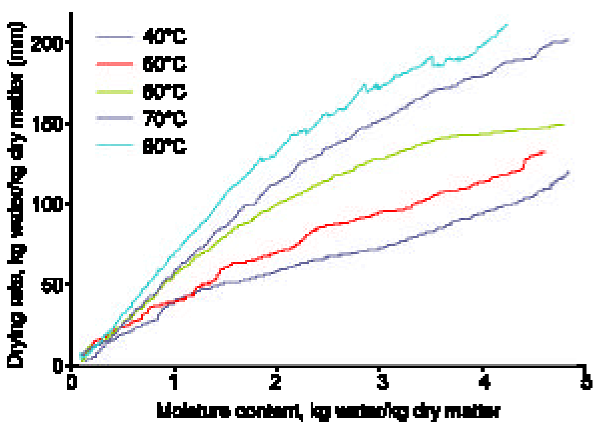

Fig. 2: Influence of temperature on drying rate of kiwifruit slices at five temperatures; air velocity of 1.5 m/s and slice thickness of 4 mm.

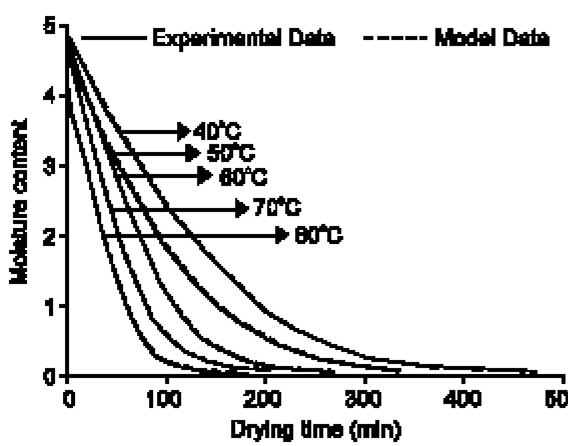

Fig. 3: Experimental and computed moisture content obtained using the Midilli model.

drying air temperature, respectively. Drying rate increased with the increase in drying air temperature, thus reducing the drying time. Midilli model had the highest value of EF (0.99932), the lowest RMSE (0.03254) and x^2 (0.00112). The Midilli model was found to satisfactorily describe the drying behavior of kiwifruit at constant air velocity 1.0 m/s and a temperature range 40-80°C.

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