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Estimation of Thin-layer Drying Characteristics of Kiwifruit (cv. Hayward) with Use of Page's Model

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Abstract: : The study of drying kinetics for fruits is necessary to give information about the time required for drying, and choosing an appropriate drying model is essential. With regards to this fact, air-drying characteristics of kiwifruit slices were investigated in a laboratory scale hot-air dryer. The thin-layer drying was carried out under five air temperatures of 40, 50, 60, 70 and 80ºC, three air velocities of 0.5, 1.0 and 1.5 m/s and three kiwifruit slice thicknesses of 2, 4 and 6 mm. Results indicated that drying took place in the falling rate period. Moisture transfer from kiwifruit slices was described by applying the Page model. The effects of drying air temperature on the model's parameters were predicted by a nonlinear regression analysis. The constant and coefficient of this model could be explained in terms of drying air temperature. The mathematical model was investigated according to the three statistical parameters of coefficient of modeling efficiency (EF), chi-square (χ^2) and Root Means Square Error (RMSE) between the observed and predicted moisture ratios. The slice thickness of 2 mm and drying air velocity of 1.5 m/s was found to be the best combination for describing the drying curves of kiwifruit slices with the highest EF (0.999269) and the lowest RMSE (0.008065) and χ^2 (0.000065). The effects of drying air temperatures on the drying constant and coefficient of the Page model were also shown.

Key words: Kiwifruit , Kinetics drying , Thin layer, Page model

INTRODUCTION

Kiwifruits have very short shelf-life because of softening and vitamin loss during storage even at refrigerated conditions [1]. In order to extend their shelf-life, kiwifruits like most fresh fruits, need preservation in some form. A growing resistance of consumers to the use of chemicals for food preservation and the increasing popularity of high quality fast-dried foods with good rehydration properties are now leading to a renewed interest in drying operations. From a technological point of view, dehydration is often the final step in an industrial food process and determines, to a large extent, the final quality of the product being manufactured [2]. One important aim of drying of agricultural productions is reduction in crop losses and improvement in the quality of dried products. Simulation models are used for the design and operation of dryers. Several researchers have developed simulation models for natural and forced convection drying systems [3]. In the past 60 years, the study of drying behavior of different materials has been the subject of interest for various investigators on both theoretical and practical grounds. In the course of studies conducted regarding the drying behavior of various agricultural products, many mathematical models have been used to describe the drying process of which thin-layer drying models are the most common models. Drying of many fruits and other agricultural products has been successfully predicted [4-7]. Simal *et al*. [8] studied drying kinetics of kiwifruit for average moisture contents from 4.65 to 0.15 kg water/kg dry mass.

In this study, the page model was used for simulation of different drying kinetics conditions of kiwifruit slices and goodness of fit was investigated as well.

MATERIALS AND METHODS

Sample preparation: *Hayward* is a major kiwifruit variety that is grown in Iran; therefore, this cultivar was considered in the study. As soon as freshly harvested kiwifruits (*Actinidia chinensis*) were obtained, samples

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were rinsed and thinly sliced in three different thicknesses of 2, 4 and 6 mm using a cutting machine. The drying experiment was conducted at five temperature levels of 40, 50, 60, 70 and 80°C using Three drying air velocities of 0.5, 1.0 and 1.5 m/s, with three replications. The dryer was adjusted to a preset temperature for about half an hour prior to achieve the steady state. Then, about 150 g of the fresh kiwifruit slices was uniformly spread in a square basket in a single layer. During the course of the drying process, kiwifruit slices were weighed using a digital balance connected to a computer. The relative humidity and temperature in the dryer were measured and recorded every 5 seconds. The drying process was continued until the drying rate reached zero. The samples were then placed in an oven of 65ºC for 24 h [9] in order to find the moisture content according to the following equation:

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

where, M is the kiwifruit slice moisture content (d.b.), W_w is the wet weight and W_d the dried weight of the sample. Experiments were conducted in triplicate.

Evaluation of the model: The Moisture Ratio (MR) of kiwifruit slices during drying experiments were calculated using Eqs. (2):

$$MR = \frac{M}{M_0} \quad (2)$$

Where, M_0 is the initial moisture content. Iguaz *et al.* [6] used Page model in which two constants were applied as empirical modification to correct for its shortcomings. This model has produced good fits to describe drying of many foods and agricultural products. The model is expressed as Doymaz [10] and Sacilik. and Elicin[11]:

$$MR = \exp(-kt^N) \quad (3)$$

where k and N are empirical constant and coefficient, respectively. The goodness of fit was determined using the three statistical parameters, i.e. modeling efficiency (EF), the reduced chi-square (χ^2) and the root mean square error (RMSE). These parameters are described in Eqs. (4-6):

Table 1: Specifications of measurement instruments including their rated accuracy

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

$$\chi^2 = \frac{\sum_{i=1}^{n}(MR_{exp,i} - MR_{pre,i})^2}{N - n} \quad (4)$$

$$RMSE = \left[\frac{1}{N}\sum_{I=1}^{n}(MR_{pre,i} - MR_{exp,i}\right]^{1/2} \quad (5)$$

$$EF = \frac{\sum_{i=1}^{N}(MR_{i,exp} - MR_{i,exp_{mean}})^2 - \sum_{i=1}^{N}(MR_{i,pre} - MR_{i,exp})^2}{\sum_{i=1}^{N}(MR_{i,exp} - MR_{i,exp_{mean}})^2} \quad (6)$$

where $MR_{exp,i}$ is the ith experimental moisture ratio, $MR_{pre,i}$ is the ith predicted moisture ratio, N is the number of observations, n is the number of constants in the drying model and $MR_{exp_{Mean}}$ is the mean value of experimental moisture ratio [12, 13].

Thin-layer drying equipment: Drying experiments were performed in a cabinet laboratory type dryer installed in the Agricultural Machinery Engineering Department of Tehran University, Karaj, Iran [14]. The dryer used for the experimental work consists of a fan, heaters, a drying chamber and instruments for various measurements (Table 1).

RESULTS AND DISCUSSION

Drying of kiwifruit slices started with initial moisture content around 4.31-4.85 (d.b.) and continued until no further changes in their mass were observed. The model coefficient and constant were related to drying air temperatures using the nonlinear regression method [15, 16]. The statistical analysis results applied to these models by taking into account all the temperature values, are given in Table 2. The relations between model coefficient and constant with temperature were described in equations from as (7) and is shown in Table 3:

Table 2: Investigation of Page model for simulation of different drying kinetics conditions of kiwifruit slices using three statistical indicators

EF	χ^2	RMSE	Velocity	Thickness
0.997955	0.000188	0.013119	0.5	2
0.997699	0.000201	0.000210	0.5	4
0.995218	0.000404	0.019261	0.5	6
0.996097	0.000298	0.015010	1.0	2
0.997818	0.000168	0.012836	1.0	4
0.996779	0.000254	0.017324	1.0	6
0.999269	0.000065	0.008065	1.5	2
0.998296	0.000132	0.010852	1.5	4
0.998594	0.000121	0.011021	1.5	6

Table 3: The relation between coefficient and constant of the Page model and temperature through the regression method for different thicknesses, temperatures and velocities

R^2	Model of N	R^2	Model of k	Velocity (m/s)	Thickness (mm)
0.911	$10.777936-0.37715T+0.00359663T^2$	0.811	$-0.035239186+0.001565028T-0.000013107T^2$	0.5	2
0.955	$2.5933-0.704979T+0.00071145\ T^2$	0.842	$-0.005132+0.000347T-0.00000225\ T^2$	0.5	4
0.664	$4.03096-0.112052T+0.0009521\ T^2$	0.736	$-0.011326+0.0005129-0.000003486T^2$	0.5	6
0.460	$2.04788-0.025316T+0.000216252T^2$	0.759	$-0.008384145+0.0003088-0.00000155\ T^2$	1.0	2
0.980	$0.60498+0.0218756T-0.0001634\ T^2$	0.979	$0.0042517-0.00012228T+.0000014281\ T^2$	1.0	4
0.460	$0.495229+0.0253718T-0.0002030T^2$	0.813	$1-.9931T+.0000018649\ T^2$	1.0	6
0.823	$-14.03789+0.532376T-0.0040269\ T^2$	0.926	$1-0.9931T+0.9778\ T^2$	1.5	2
0.646	$-0.6966+0.064376T-0.00052516T^2$	0.982	$0.0270403-0.0009081T+0.000010487T^2$	1.5	4
0.536	$2.2371-0.056873T+0.00055545\ T^2$	0.809	$-0.0048438+0.00031102T-0.00000131697\ T^2$	1.5	6

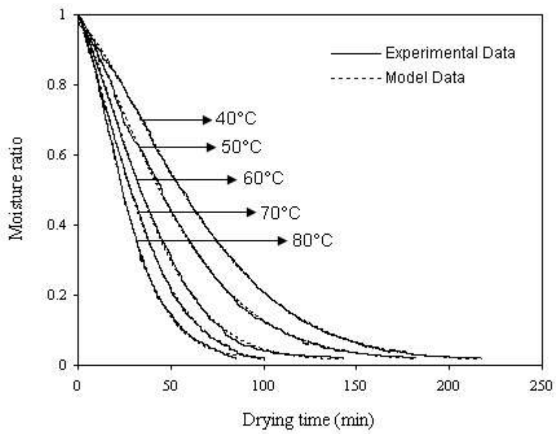

Fig. 1: Variation of experimental and predicted moisture ratio with drying time by the Page model for the slice thickness of 2 mm and drying air velocity of 1.5 m/s

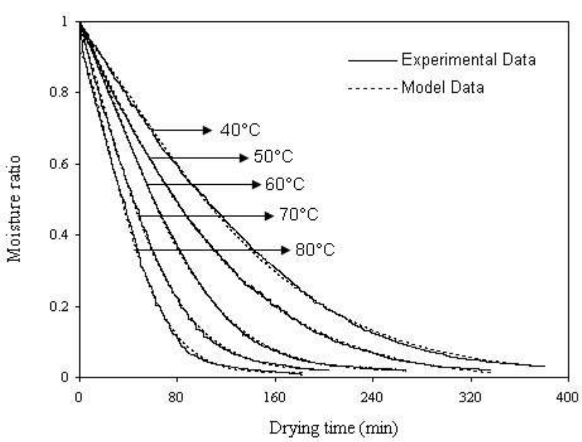

Fig. 2: Variation of experimental and predicted moisture ratio with drying time by the Page model for the slice thickness of 4 mm and drying air velocity of 1.5 m/s

$$k,N = a + bT + cT^2 \tag{7}$$

The highest EF (0.999269) value and the lowest RMSE (0.008065) and χ^2 (0.000065) values were found

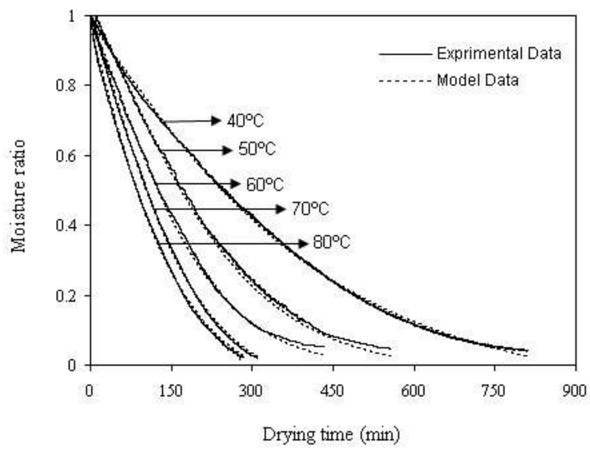

Fig. 3: Variation of experimental and predicted moisture ratio with drying time by the Page model for the slice thickness of 6 mm and drying air velocity of 1.5 m/s

at the slice thickness of 2 mm and drying air velocity of 1.5 m/s followed by the slice thickness of 6 mm and drying air velocity of 1.5 m/s. The lowest EF (0.995218) value and the highest RMSE (0.019261) and χ^2 (0.000404) values were found at the slice thickness of 6 mm and drying air velocity of 0.5 m/s.

Figure 1-3 show the drying curves of kiwifruit slices at different drying air temperatures, from 40 to 80ºC and variation of experimental and predicted moisture ratios with drying time by the Page model at the slice thicknesses of 2, 4 and 6 mm and drying air velocity of 1.5 m/s. As it was expected, air temperature affected the drying curves decreasing the drying time of samples.

Based on the multiple regression analysis, constant and coefficient were expressed in terms of the drying air temperature by Page model as (for thickness of 4mm and drying air velocity of 1.0 m/s):

$$K = 0.0042517-0.00012228T+0.0000014281\ T^2,\ R^2 = 0.979$$

$$N = 0.60498+0.0218756T-0.0001634\ T^2,\ R^2 = 0.98$$

Rafiee *et al*. [17] showed that the drying constant and coefficient of the Page model can be shown to be linearly dependent on temperature based on the multiple regression analysis for wheat.

The drying time becomes shorter with higher temperatures, which was expected due to an increase in the drying rate. This increase is due to the increased heat transfer potential between the air and kiwifruit slices, thus, enhancing the evaporation of water from kiwifruit slices. The effect of temperature on the condition of drying is well documented in the literature [18].

Simal *et al*. [8] reported that once compared the three proposed models (exponential, Page's and diffusional models), it could be concluded that the Page model provided the best simulation of the drying curves of kiwi cubes (average %var = 99.6±0.2%) whereas the exponential model provided the poorest simulation (average %var =98.0±1.4%).

CONCLUSIONS

In the present study, drying of kiwifruit occurred only in the falling rate stage. The drying behavior of kiwifruit (*Hayward*) was fitted with the Page model with nonlinear temperature dependence of constants. Page model showed a good fit for all conditions. The highest EF (0.999269) value and the lowest RMSE (0.008065) and χ^2 (0.000065) values of Page model was at the slice thickness of 2 mm and drying air velocity of 1.5 m/s followed by the slice thickness of 6 mm and drying air velocity of 1.5 m/s.

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