EVALUATION OF THIN-LAYER DRYING MODELS FOR JERUSALEM ARTICHOKE (*Helianthus tuberosus* L.) TUBERS IN DIFFERENT DRYING METHODS

Orraya Porniammongkol, Wasan Duangkhamchan* and Sudathip Inchuen

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Abstract

This paper presents the evaluation of thin-layer models for Jerusalem artichoke (*Helianthus tuberosus* L.) tubers in different drying methods. Slices of Jerusalem artichoke were dried in a hot-air oven at 60°C, in a microwave oven at 200 W, under open-air sun, and under shade until a moisture content of approximately 10% (dry basis) was reached. In addition, blanching was used in order to investigate the influence of pre-treatment. The experimental data of the drying kinetics was fitted to various well-known theoretical models using nonlinear regression analysis. The suitable choice of prediction was made based on the coefficient of determination (R^2), the root mean square error (RMSE), and the chi-square (χ^2). Among several drying models tested, the Midilli *et al.* model gave the best fit for the convective hot-air drying and microwave drying methods for both blanched and unblanched samples, while the approximation of diffusion model and the modified Page model were the best for the shade drying of the blanched and unblanched samples, respectively. In addition, the experimental results obtained by the open-air sun drying method were suitably fitted to the Midilli *et al.* model and the approximation of diffusion model for the blanched and unblanched samples, respectively. The effective diffusivity coefficient, D_{eff}, for the different drying methods was estimated, ranging from 0.16515×10^{-9} m²/s to 15.6450×10^{-9} m²/s. Furthermore, in order to investigate the effect of the drying methods on the quality of Jerusalem artichoke powders, the color and browning index were determined. It was found that the drying methods and pre-treatment affected the color and browning index of Jerusalem artichoke powders.

Keywords: **Jerusalem artichoke, drying kinetics, diffusivity coefficient, drying model, browning index**

Introduction

Jerusalem artichoke (*Helianthus tuberosus* L.) is a perennial vegetable plant with a high sugar content (Wang *et al.*, 2013; Matías *et al.*, 2011). Similar to potato, it consists of tubers in which valuable nutrients are accumulated (Baltacioğlu *et al.*, 2012). Jerusalem artichoke, which originated from North America, grows well in poor soil with a high tolerance to frost

Department of Food Technology and Nutrition, Faculty of Technology, Mahasarakham University, Kamriang, Kantarawichai, Mahasarakham 44150, Thailand. Tel. 0-4375-4085; Fax. 0-4375-4069; E-mail: wasan.d@msu.ac.th

* *Corresponding author*

and various plant diseases (Ge *et al*., 2010) irrespective of climate conditions (Saengthongpinit and Sajjaanantakul, 2005; Takeuchi and Nagashima, 2011; Baltacıoğlu and Esin, 2012) and without any special breeding technique. Therefore, its tubers can be produced worldwide (Takeuchi and Nagashima, 2011; Baltacıoğlu and Esin, 2012). Besides being known as an alternative source of carbohydrate and inulin (14-15%) (Nadir *et al*., 2011), Jerusalem artichoke tubers contain 79.8% water, 16.6% carbohydrate, 1% protein, 16.6% crude fiber, 2.8% ash (Jilu *et al*., 2003), and traces of polyphenol (Baltacıoğlu and Esin, 2012). As a result of containing a high amount of inulin, a non-digestible oligosaccharide, instead of starch as a carbohydrate reserve, Jerusalem artichoke tubers have been increasingly used as a functional food ingredient in various foods. Consequently, many attempts have been made to use the tubers to prevent diabetes and to use them as an anti-carcinoma agent, (Kaur and Gupta, 2002; Pan *et al*., 2009). In addition, they have been used in the diet of patients with certain diseases due to their containing low amounts of polyamines (Righetti *et al*., 2008). From this point of view, consumption of Jerusalem artichoke in the daily diet may support healthier lives of the consumers (Baltacıoğlu and Esin, 2012). However, due to changes in consumer lifestyles, alternative forms of Jerusalem artichoke tubers, commonly eaten as a vegetable, have been processed to meet the new requirements (Gedrovica and Karklina, 2011). Among various products, including powders, juices, extracted inulin, fructose, and fructo-oligosaccharide (Nadir *et al*., 2011), Jerusalem artichoke processed as a powder could well be applied as an ingredient in food applications (Gedrovica and Karklina, 2011). The Jerusalem artichoke powders are commonly prepared by drying slices at either 60 or 70^{o}C in an oven for 5 h or until the expected moisture content is reached. The dried slices of Jerusalem artichoke tubers are subsequently milled to produce a fine powder with particles less than 1.0 mm in diameter (Takeuchi and Nagashima, 2011).

In addition to serving as a traditional method of food preservation, drying is also used for the production of special foods and food ingredients (Evin, 2012; Maroulis and Saravacos, 2003; Zhang *et al*., 2006). Up until now, many drying techniques have been investigated for energy efficiency, operating cost, and the effects on the finished product properties (Mota *et al*., 2010; Tulek, 2011; Therdthai and Zhou, 2009; Doymaz, 2004; Toğrul and Pehlivan, 2004; Evin, 2012; Olawale and Omole, 2012; Mirzaee *et al*., 2010; Midilli *et al*., 2002). Open-air sun drying is an immemorial method to dry grains, vegetables, fruits, and other agricultural products. It brings an advantage in terms of being a low cost operation. However, this technique is not taken into consideration when large-scale production is concerned due to a lack of ability to control the drying operation properly, the long drying time, weather uncertainties, high labor costs, a large area requirement, and so on (Toğrul and Pehlivan, 2004). Hot-air drying is known as a common technique providing more energy efficiency, ease, and convenience of operation compared with open-air sun drying. Moreover, microwave drying is an alternative method in which the drying time is greatly reduced by applying microwave energy to the drying material, resulting in quality remaining in the finished product (Evin, 2012).

Mathematical modeling, recognized as an effective technique for the design and optimization of processes, has been widely used for analyzing a drying process for agricultural and food products (Cao *et al*., 2003). Many attempts focusing on this technique have been made to account for thin layer equations describing the drying phenomena in a unified way, regardless of the controlling mechanism (Mota *et al*., 2010; Tulek, 2011; Therdthai and Zhou, 2009; Evin, 2012; Olawale and Omole, 2012; Mirzaee *et al*., 2010; Midilli *et al*., 2002). To our knowledge, little information has been reported on the drying behavior of Jerusalem artichoke (*Helianthus tuberosus* L.) tubers which can be used as a basis for design and process optimization. Therefore, the main objectives of this study are to: (1) investigate the drying kinetics of Jerusalem artichoke tubers for different drying methods, (2) model the thin layer drying of Jerusalem artichoke tubers by fitting well-known mathematical drying models to the experimental data obtained by different drying methods, (3) calculate the effective diffusivities of Jerusalem artichoke tubers for different drying methods, and (4) investigate the influences of the drying method and blanching as a pretreatment on the physical properties of dried Jerusalem artichoke tubers.

Materials and Methods

Mathematical Descriptions

Thin-layer Drying Models

To account for the thin-layer drying characteristics, a one-parameter, 2 two-parameter, 2 three-parameter, and 2 four-parameter models used in this work are listed below (For more details concerning each of the following models, the reader should refer to Celma *et al*., 2007):

One parameter

Lewis

$$MR = e^{-kt} \tag{1}$$

Two parameters

Modified Page

$$MR = e^{(-(-kt)^{n})} \tag{2}$$

Henderson and Pabis

$$MR = ae^{(-kt)} \tag{3}$$

Three parameters

Logarithmic

$$MR = ae^{(-kt)} + c \tag{4}$$

Approximate of diffusion

$$MR = ae^{(-kt)} + (1 - a)e^{(-kbt)} \tag{5}$$

Four parameters

Two term

$$MR = ae^{(-k_0 t)} + be^{(-k_1 t)} \tag{6}$$

Midilli *et al.*

$$MR = ae^{(-kt^{n})} + bt \tag{7}$$

where MR is the moisture ratio ($MR = (M_t - M_e)/(M_i - M_e)$); M_t is a moisture content at a certain time (g water/g dry solid), M_e is an equilibrium moisture content (g water/g dry solid), and Miis an initial moisture content (g water/g dry solid). t is the drying time (min). a, b, c, k, k_1, and k_0 are an equation's constant, and n is a power constant.

A non-linear regression analysis was initially used to determine the best fitted values of the parameters for each drying condition. The quadratic functions were subsequently formulated to provide the exact fitting relationship between the drying temperature and the parameters obtained in the drying equation. The accuracy of fit was evaluated by the coefficient of determination (R^2), the root mean square error (RMSE), and the reduced chi-square (χ^2). The RMSE and χ^2 can be calculated as follows:

$$RMSE = \sqrt{\frac{1}{N}\sum_{i=1}^{N}\left(V_{obs,i} - V_{pre,i}\right)^2} \tag{8}$$

$$\chi^2 = \frac{\sum_{i=1}^{N}\left(V_{obs,i} - V_{pre,i}\right)^2}{N - z} \tag{9}$$

where V_{obs} and V_{pre} are the observed value and the corresponding predicted value according to the model being used, N is the number of observations, and z is the number of parameters, e.g. a, b, c, k, k_1 and k_0, used in each equation. In the above equations, the RMSE and χ^2 aim at comparing the consistency between the experimental and predicted moisture ratios, and when they approach zero it indicates that the prediction is closer to the experimental data (Mota *et al*., 2010; Lee and Kim, 2009; Roberts *et al*., 2008).

Estimation of the Effective Diffusivities (D_{eff})

As mostly taking place in food materials, the falling-rate period plays an important role in the drying as the moisture transfer is dominated by internal diffusion (Tulek, 2011).

Crank (1975) has expressed the diffusion according to Fick's second law for unsteady state to describe the drying process during the falling-rate period as follow:

$$\frac{\partial M}{\partial t} = \nabla\left(D_{eff}\left(\nabla M\right)\right) \tag{10}$$

where D_{eff} is the effective moisture diffusivity (m^2/s) representing the conductive term of all moisture transfer mechanisms, M is the moisture content (dry basis), and t is time (s).

Assuming a uniform initial moisture content, constant effective diffusivity throughout a thin layer sample, and negligible shrinkage, the analytical solution of Equation (10) given by Crank (1975) is expressed by:

$$MR = \frac{M(t) - M_e}{M_i - M_e} = \frac{8}{\pi^2}\sum_{n=0}^{\infty}\frac{1}{(2n+1)^2}\exp\left[-\frac{(2n+1)^2\pi^2 D_{eff} t}{4L^2}\right] \tag{11}$$

where L is the half thickness of the thin layer sample (m), and n is a positive integer. In practice, only the first term of Equation (11) is considered, yielding:

$$MR = \frac{8}{\pi^2}\exp\left(-\frac{\pi^2 D_{eff} t}{4L^2}\right) \tag{12}$$

Taking the natural logarithm, Equation (12) becomes a straight line of the form $y = y_0 + ax$, as follows:

$$\ln MR = \ln\frac{8}{\pi^2} + \left(-\frac{D_{eff}\pi^2}{4L^2}\right)t \tag{13}$$

where

$$y_0 = \ln\frac{8}{\pi^2} \tag{14}$$

$$a = -D_{eff}\left(\frac{\pi^2}{4L^2}\right) \tag{15}$$

Thus, the effective moisture diffusivity (D_{eff}) can be estimated for each operating condition from the slope (a) of the plot of ln (MR) as a function of time (t), Equation (15).

Drying Experiments

Samples

Freshly cultivated Jerusalem artichoke tubers were purchased from a farm located in the North East of Thailand. They were sorted according to uniform maturity and size. After being cleaned, the Jerusalem artichoke tubers were peeled and subsequently sliced to 1 mm thickness to provide the thin layer samples. The prepared Jerusalem artichoke samples were divided into 2 portions. The fresh portion served as the control, while the remaining portion was blanched in order to reduce the initial microbial load and inactivate enzymes. The blanched samples were blanched in boiling water for 1 min and subsequently cooled under running tap water. Prior to the drying processes, the average initial moisture contents of each portion were determined using the AOAC method (AOAC, 2002).

Drying Procedures

Each of the prepared portions mentioned previously was dried by a different drying method including convective hot-air drying, microwave drying, open-air sun drying, and shade drying. The slices of Jerusalem artichoke tubers were dried in a hot-air oven at 60°C, in a microwave oven at 200 W, under open-air sun, and under shade until a moisture content of approximately 10% (dry basis) was reached. During the drying processes, the moisture contents of the samples were determined at different time intervals; 10, 2, 120, and 360 min, for hot air drying, microwave drying, open-air sun drying, and shade drying, respectively. The dried samples obtained by all the drying methods were immediately ground to provide Jerusalem artichoke powders for further analyses. They were subsequently packed in aluminium foil and stored in a a freezer to prevent additional moisture from the surroundings until being used for various physical analyses. Both the dried samples with and without pre-treatment were physically analyzed for the browning index and color, as follows.

Soluble materials were extracted by

incubating 1.0 g of the dried powder with 15 ml distilled water for 20 min at 80°C (Takeuchi and Nagashima, 2011). They were subsequently filtered with No.1 Whatman paper. The filtrate was diluted with an equal volume of 95% ethanol and then centrifuged at 4000 rpm at 4°C for 15 min. The absorbance of the supernatant was measured at 420 nm using a spectrophotometer. The browning index was expressed in terms of the absorbance (Abs)/g dry mater (Inchuen, 2009).

The color of the fresh and dry-powdered Jerusalem artichoke was measured using a Minolta CR 300 colorimeter (Konica Minolta Inc., Tokyo, Japan). The color system used was Hunter L^* a^* b^* (considering the standard illumination D_{65} and observer 2°). The color brightness coordinate L^* measured the whiteness value, ranging from black at 0 to white at 100. The chromaticity coordinate a^* measured red when positive and green when negative, and the chromaticity coordinate b^* measured yellow when positive and blue when negative (Inchuen, 2009).

Results and Discussion

Evaluation of Thin-layer Drying Models

Thin-layer drying experiments of blanched and unblanched Jerusalem artichoke samples were performed by means of different methods including convective hot-air drying, microwave drying, shade drying, and open-air sun drying. The initial moisture contents of the blanched and unblanched samples, approximately 600-740% (dry basis), decreased until a certain moisture content less than 10% (dry basis) or the equilibrium moisture content were reached for each drying condition, as shown in Figure 1(a-d). It was found from this Figure that, with various drying methods, obvious differences in the drying times were observed. Among the drying methods tested, microwave drying took the shortest time to reach the desired moisture content, followed by hot air, open-air sun, and shade drying. This could be explained by the larger driving force for heat transfer. This was also the of Karacabey *et al.* (2011). Similar results were observed for the blanched Jerusalem artichoke slices. However, it was found from Figure 1(a-d) that blanching affected the drying kinetics of the samples, a lower drying rate at the period before reaching the equilibrium for all drying methods. This trend was opposite to the behavior found in literature (Leeratanarak *et al.*, 2006; Kuitche *et al.*, 2007; Olawale and Omole, 2012) in which the blanched samples were observed to dry faster than the unblanched ones. The excessive blanching time decreasing the rate of moisture removal could be a possible explanation. Leeratanarak *et al.* (2006) investigated the effect of the blanching time on the drying rate of potato chips in different drying methods. They found that a suitable blanching time could facilitate the moisture movement, otherwise an excess water content absorbed during longer blanching was found, resulting in a lower drying rate.

In order to assess the suitable choice for using the thin-layer drying models for Jerusalem artichoke tubers, the highest R^2 values, and the lowest RMSE and χ^2 values were used as a criterion. The goodness-of-fit values for each of the drying conditions obtained from the thin-layer drying models proposed in the literature (Equations 1-7) are presented in Tables 1-4. The results showed that the model expressed by Midilli *et al.* (2002), containing 4 parameters gave the best consistency with the experimental data for the convective hot-air drying and the microwave drying methods for both the treated and untreated samples. It obtained the highest R^2 and the lowest RMSE. However, when comparing the χ^2, the coefficient of performance based on both a number of data and parameters being used in a model, the modified Page model gave a value closer to zero, meaning that this model was more suitable when the complexity of the model parameters was concerned. From this, it could be confirmed that, besides the modified Page and logarithmic models which were found to be the best in many instances (Falade and Solademi, 2010; Doymaz, 2011), the Midilli *et al.* (2002) model was useful for practical proposes. This finding is in agreement with other results reported for microwave drying of Jerusalem artichoke tubers (Karacabey *et al.*, 2011) and other products such as apricot and ginger reported by Mirzaee *et al.* (2010) and Loha *et al.* (2012), respectively. However, factors such as the types of samples, drying conditions, and drying methods are known as influences on the drying kinetics, resulting in the different drying models used (Olawale and Omole, 2012). It was evident in this work that not only was the Midilli *et al.* (2002) model a good fit to the experimental data, but others such as the approximation of diffusion model and the modified Page model were also good choices, especially for the shade drying and for the blanched and unblanched samples, respectively (Table 3). In addition, Table 4 shows that the model proposed by Midilli *et al.* (2002) and the approximation of diffusion model were considered to be the most suitable ones for the treated and untreated samples dried by the open-air sun drying method, respectively. The model parameters of the selected thin-layer drying models for each of the drying methods and both the blanched and unbleached Jerusalem artichoke samples are presented in Table 5.

Estimation of diffusivity coefficient (D_{eff})

Table 6 presents the results of the fitting to Equation (13), which allowed for the calculation of the values of the diffusivity coefficients, D_{eff}, for the different drying methods by Equations (14) and (15). The values of the correlation coefficients varied

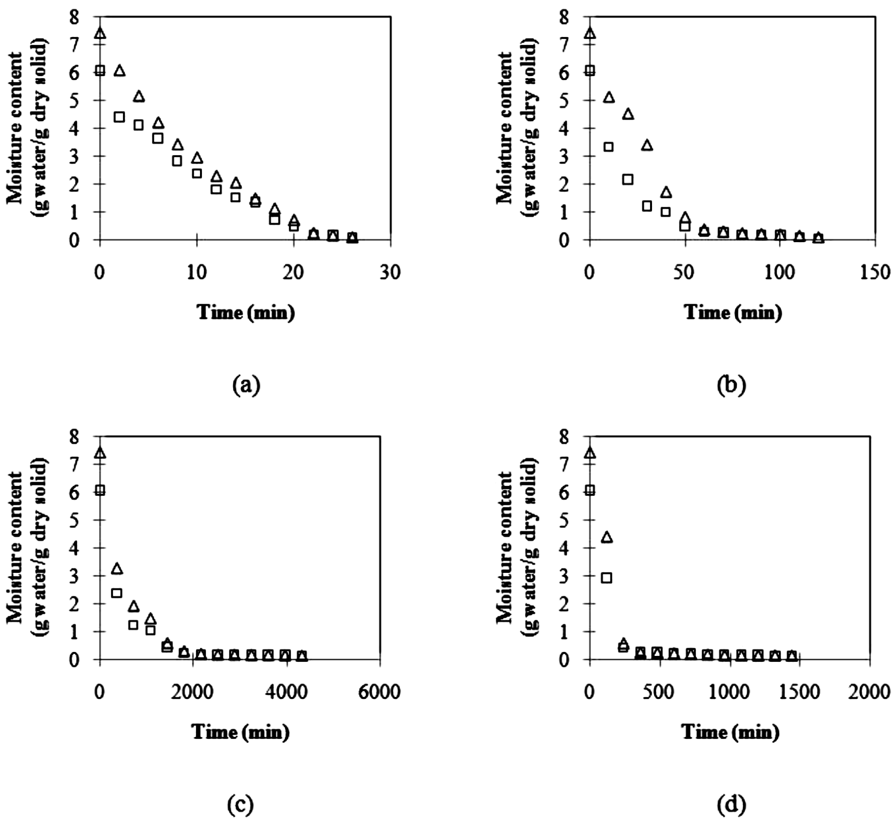

Figure 1. Drying kinetics of Jerusalem artichoke tubers in (a) microwave drying, (b) hot-air drying, (c) shade drying, and (d) open-air sun drying; blanched (triangle) and unblanched square)

from 0.91848 for the microwave drying of the blanched samples to 0.98773 for the shade drying of the blanched samples. It could also be observed from Table 6 that the effective diffusivity coefficients were different with the various drying methods used for both the blanched and unblanched samples. The microwave drying gave the maximum D_{eff} of 15.6450×10^{-9} m^2/s and 15.6399×10^{-9} m^2/s for the blanched and unblanched samples, respectively, followed by the hot-air, open-air sun, and shade drying for both the treated and untreated samples. It could be explained by the fact that, in microwave drying, the thermal energy used for heat transfer was higher compared with other drying methods investigated in this work, resulting in a larger driving force and higher moisture diffusivity.

Color and Browning Index

Table 7 illustrates the color values and the browning index of Jerusalem artichoke powder obtained from sliced tubers dried by different methods under pre-treatment conditions. In the case of lightness (L^*), the drying method significantly affected the lightness of both the blanched and unblanched samples. The L^* value of the dried samples obtained by the hot-air drying was highest, followed by the open-air sun drying, the shade drying, and the microwave drying. In microwave drying, the dried blanched and unblanched Jerusalem artichoke tuber slices were darkest probably due to heat damage resulting from an inappropriate microwave output power (200 W) that was used. When

Table 1. The goodness-of-fit values for the convective hot-air drying

Model name	Blanched			Unblanched		
	R^2	RMSE	χ^2	R^2	RMSE	χ^2
Lewis	0.971	0.054	0.0032	0.995	0.0206	0.0005
Modified Page	0.982	0.042	0.0021	0.998	0.0123	0.0002
Henderson&Pabis	0.972	0.053	0.0033	0.995	0.0199	0.0005
Logarithmic	0.976	0.049	0.0031	0.997	0.0152	0.0003
Approximation of diffusion	0.982	0.042	0.0023	0.998	0.0128	0.0002
Two-term	0.972	0.053	0.0041	0.998	0.0128	0.0002
Midilli *et al.*	**0.983**	**0.041**	**0.0024**	**0.998**	**0.0117**	**0.0002**

Table 2. The goodness-of-fit values for the microwave drying

Model name	Blanched			Unblanched		
	R^2	RMSE	χ^2	R^2	RMSE	χ^2
Lewis	0.985	0.0363	0.0014	0.975	0.0461	0.0023
Modified Page	0.991	0.0280	0.0009	0.978	0.0437	0.0022
Henderson&Pabis	0.986	0.0352	0.0014	0.976	0.0461	0.0025
Logarithmic	0.998	0.0141	0.0002	0.989	0.0307	0.0012
Approximation of diffusion	0.992	0.0268	0.0009	0.978	0.0418	0.0022
Two-term	0.986	0.0352	0.0017	0.976	0.0461	0.0030
Midilli *et al.*	**0.998**	**0.0127**	**0.0002**	**0.991**	**0.0285**	**0.0011**

compared to the faster hot-air drying, the shade and open-air sun drying utilizing lower thermal energy obtained darker dried samples, resulting from the browning effect.

Regarding the redness of the dried Jerusalem artichoke tuber slices, the drying method significantly affected the a^* value for the blanched samples, ranging from 1.267 ± 0.115 to 2.967 ± 0.058. A different trend could be observed for the unblanched samples. The redness of Jerusalem artichoke tuber slices dried by the microwave and shade drying methods was similar and the highest compared with the redness obtained by the other 2 methods. The effect of the browning reaction could be a possible explanation for the shade drying, while burning may cause the redder microwave-dried samples. For the effect of pre-treatment, the redness of the blanched Jerusalem artichoke tuber slices highly decreased in the microwave drying. This influence was probably due to the excessive water absorbed during blanching which was not affected by heat damage resulting in redder dried samples, compared with the unblanched ones at the same microwave power and drying time. The decrease in the a^* value was also found for the shade drying of the blanched Jerusalem artichoke tuber slices. In the case of shade drying, the effect of blanching on the redness could be explained by the browning reaction taking place during the long period of drying. In contrast, unexpected redder samples were observed for the blanched samples in the open-air sun drying. However, the influence of blanching was not observed with regard to the hot-air drying.

Table 3. The goodness-of-fit values for the shade drying

Model name	Blanched			Unblanched		
	R^2	RMSE	χ^2	R^2	RMSE	χ^2
Lewis	0.987	0.0314	0.0011	0.982	0.0361	0.0014
Modified Page	0.996	0.0172	0.0003	**0.997**	**0.0156**	**0.0003**
Henderson&Pabis	0.988	0.0305	0.0011	0.983	0.0355	0.0015
Logarithmic	0.793	0.1258	0.0211	0.848	0.1058	0.0149
Approximation of diffusion	**0.996**	**0.0165**	**0.0004**	0.996	0.0161	0.0003
Two-term	0.996	0.0165	0.0004	0.996	0.0161	0.0004
Midilli *et al.*	0.656	0.1623	0.0395	0.758	0.1336	0.0268

Table 4. The goodness-of-fit values for the open-air sun drying

Model name	Blanched			Unblanched		
	R^2	RMSE	χ^2	R^2	RMSE	χ^2
Lewis	0.961	0.0593	0.0035	0.979	0.0418	0.0017
Modified Page	0.992	0.0243	0.0007	0.989	0.0280	0.0009
Henderson&Pabis	0.962	0.0585	0.0037	0.979	0.0415	0.0019
Logarithmic	0.963	0.0578	0.0040	0.982	0.0379	0.0017
Approximation of diffusion	0.993	0.0240	0.0007	**0.990**	**0.0280**	**0.0009**
Two-term	0.962	0.0585	0.0046	0.979	0.0415	0.0023
Midilli *et al.*	**0.997**	**0.0165**	**0.0004**	0.929	0.0761	0.0077

Table 5. The parameters of the selected models for different drying methods

Drying methods	Pre-treatment	Model	Parameters
Hot air	blanched	Midilli *et al.*	a = 0.960443
			k = 0.007894
			n = 1.400880
			b = 0.000046
	unblanched	Midilli *et al.*	a = 0.998983
			k = 0.077100
			n = 0.881481
			b = 0.000076
Microwave	blanched	Midilli *et al.*	a = 0.999493
			k = 0.094409
			n = 0.927417
			b = -0.005727
	unblanched	Midilli *et al.*	a = 0.986608
			k = 0.119185
			n = 0.793363
			b = 0.008575
Shade	blanched	Approximation of diffusion	a = 0.278727
			k = 0.038315
			b = 0.035445
	unblanched	Modified Page	k = 0.002587
			n = 0.668000
Open-air sun	blanched	Midilli *et al.*	a = 1.009899
			k = 0.000045
			n = 1.971890
			b = 0.000024
	unblanched	Approximation of diffusion	a = -1.68387
			k = 0.168116
			b = 0.085320

Table 6. Estimated effective diffusivity coefficients for different drying methods

Method	Blanched				Unblanched			
	R^2	y_0	a	D_{eff} (x $10^{-9}m^2/s$)	R^2	y_0	a	D_{eff} (x $10^{-9}m^2/s$)
Hot air	0.959	0.0046	-0.0401	4.0609	0.964	-0.3923	-0.0359	3.6374
Micro-wave	0.918	0.4118	-0.1544	15.6450	0.932	0.3719	-0.1544	15.6399
Shade	0.988	-0.0908	-0.0016	0.1651	0.974	-0.2424	-0.0016	0.1581
Open-air sun	0.949	0.1987	-0.0099	1.0010	0.943	0.0617	-0.0093	0.9473

Table 7. Browning Index and color in terms of L* a* b* values of dried Jerusalem artichoke powder in different drying methods

Pre-treatment	Drying method	L^*	a^*	b^*	Browning Index
unblanched	Fresh	-	-	-	${}_{A}0.119 \pm (0.001)^{c}$
	Microwave drying	${}_{A}51.533 \pm (0.231)^{d}$	${}_{A}5.100 \pm (0.173)^{a}$	${}_{ns}17.067 \pm (0.473)^{b}$	${}_{A}0.128 \pm (0.001)^{b}$
	Hot-air drying	${}_{A}87.267 \pm (0.058)^{a}$	${}_{ns}1.233 \pm (0.153)^{c}$	${}_{B}11.667 \pm (0.321)^{d}$	${}_{A}0.123 \pm (0.001)^{bc}$
	Open-air sun drying	${}_{A}83.200 \pm (0.100)^{b}$	$B1.833 \pm (0.058)^{b}$	${}_{ns}13.333 \pm (0.252)^{c}$	${}_{A}0.119 \pm (0.002)^{c}$
	Shade drying	${}_{B}67.700 \pm (0.173)^{c}$	${}_{A}5.333 \pm (0.321)^{a}$	${}_{A}21.967 \pm (0.231)^{a}$	${}_{A}0.345 \pm (0.008)^{a}$
blanched	Fresh	-	-	-	${}_{B}0.063 \pm (0.002)^{c}$
	Microwave drying	${}_{B}49.267 \pm (0.115)^{d}$	${}_{B}1.900 \pm (0.173)^{c}$	${}_{ns}16.467 \pm (0.058)^{b}$	${}_{B}0.096 \pm (0.002)$b
	Hot-air drying	${}_{B}79.500 \pm (0.173)$a	${}_{ns}1.267 \pm (0.115)^{d}$	${}_{A}13.767 \pm (0.153)^{c}$	${}_{B}0.077 \pm (0.006)^{c}$
	Open-air sun drying	${}_{B}78.133 \pm (0.058)^{b}$	${}_{A}2.267 \pm (0.153)^{b}$	${}_{ns}13.467 \pm (0.351)^{c}$	${}_{B}0.062 \pm (0.001)^{c}$
	Shade drying	${}_{A}69.233 \pm (0.208)^{c}$	${}_{B}2.967 \pm (0.058)^{a}$	${}_{B}19.600 \pm (0.346)^{a}$	${}_{B}0.204 \pm (0.020)^{a}$

^{A,B} denote the effect of blanching, significant difference ($p < 0.05$) when using different letter.
^{a,b,c,d} denote the effect of drying method, significant difference ($p < 0.05$) when using different letter.
${}_{ns}$ denotes insignificant value.
$\pm$ Standard derivation

For the effect of the drying method and blanching of Jerusalem artichoke tuber on yellowness, an obvious trend was not observed. The different b^* values were significant with the different drying methods under the blanching condition, while the dried samples obtained by the hot-air drying and open-air sun drying were insignificant. Taking the effect of blanching into consideration, the yellowness of the samples dried by the hot-air method increased, while a decrease in this value was observed when shade drying was used. The insignificant influence of blanching was not found for the microwave and open-air sun drying.

The effects of blanching and the drying method on the browning index of Jerusalem artichoke tuber slices are also presented in Table 7. The results showed a significantly decreasing browning index for all drying methods, when regarding the influence of blanching. From this, it could be concluded that blanching in boiling water for 1 min could be sufficient to inactivate enzymes which are the cause of the browning reaction. However, so far as the effect of drying on the browning index was concerned, a trend could not be obviously captured. Surprisingly, the browning indices of both the blanched and unblanched Jerusalem artichoke tuber slices dried by open-air sun drying were lower than those of the microwave-dried and hot-air-dried samples. This might be due to the higher degree of non-enzymatic browning (Mailard reaction) occurring during microwave and hot-air drying. Since Jerusalem artichoke tubers contain high essential amino acid and reducing sugar (Aleknaviciene *et al.*, 2009), the Mailard reaction resulting from a reaction between those 2 chemicals takes place, usually requiring heat.

Conclusions

The thin-layer drying models for different drying methods and pre-treatment were evaluated in this study. The drying methods and blanching were found to have differences in the suitable selection of the theoretical models. The Midilliet al. model gave the best fit for the hot-air drying and microwave drying method for both the blanched and unblanched samples, while the approximation of diffusion model and the modified Page model were good choices for the shade drying of the blanched and unblanched samples, respectively. In the case of open-air sun drying, the Midilli *et al*. model and the approximation of diffusion model were suitable for the blanched and unbalanced samples, respectively. The effective diffusivity coefficients for the different drying methods were also estimated in this work. These values were different depending on the various drying methods and pre-treatment, ranging from 0.16515×10^{-9} m^2/s to 15.6450×10^{-9} m^2/s. The color and browning index of the Jerusalem artichoke powders were examined in order to investigate the effects of the drying methods and pre-treatment. In terms of the lightness (L^*) and browning index, the drying methods and blanching were found to have obvious effects. The L^* value of the dried samples obtained by hot-air drying was highest, followed by open-air sun drying, shade drying, and microwave drying for both the blanched and unblanched samples, while the decrease in the browning index with the use of pre-treatment was observed for all the drying methods.

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