MATHEMATICAL MODELLING OF DICED KONJAC CORMS DRYING IN A FLUIDIZED BED DRYER

by

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Konjac glucomannan (KGM) can be obtained from tubers (called corms) of various species within the Amorphophallus genus. Among the most popular species for use in food industry is Buk Nuea Sai (Amorphophallus muelleri), a native species in Thailand. Drying process can be helpful in preserving KGM during long storage periods. However, the existing drying systems are often slow and lead to drying delays and subsequently quality reduction of the dried product. Given the economic importance of KGM, new, more efficient drying systems, have to be developed. The present study focuses on the drying kinetics of konjac dices in a fluidized bed, operating at a constant air velocity of 2.5 m/s and air temperatures of 50, 60, and 70 °C. Six empirical mathematical models were selected to describe and compare the drying characteristics of konjac dices subjected to these conditions. The model coefficients were determined by non-linear regression analysis. Among the tested models used to describe the drying kinetics of konjac dices, the two-term model was found as the best one. The moisture loss from the dice was described by the Fick's diffusion equation, and based on the obtained results the effective moisture diffusivity was estimated, getting a value in the range between $9.60526 \cdot 10^{-9}$ m^2/s and $1.2006 \cdot 10^{-7}$ m^2/s. The relationship between the temperature and the effective moisture diffusivity was described adequately by means of Arrhenius-type equation. An activation energy value between 8.65 kJ/mol and 61.28 kJ/mol was obtained. The findings allow the successful simulation of konjac dice drying in a fluidized bed between 50 and 70 °C, 30-60 mm bed height and 6-15 mm dice thickness.

Key words: *konjac glucomannan, mathematical modelling, moisture diffusivity, activation energy*

Introduction

Amorphophallus sp. is the plant genus to which belong various species commonly known in English as konjac elephant foot yam. The konjac plant is a perennial plant and a member of the family of Araceae. Konjac produces large subterranean spherical tubers called corms. They consist mostly of polysaccharides namely starches and in some species glucomannan, a long chain of glucose and mannose molecules. Konjac is grown in several Asian countries such as China, Japan, and Thailand. There are 46 species of *Amorphophallus* found in Thailand, mostly in the northern part of the country. A widespread and valuable species that is used in the food industry is *Buk Nuea Sai* or *Buk Khai* (*Amorphophallus muelleri*), which is rich in glucomannan. It is a native species in Thailand, found mostly in the northern part of the country, namely in the provinces of

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Chiang Mai, Chiang Rai, Lampang, and Mae Hong Son, and in the western part of Thailand, such as in the Kanchanaburi and Tak provinces [1] *Amorphophallus muelleri* is a valuable commercial species since it shows high tolerance towards high ambient temperatures, water stress, and soil-borne diseases. It also has a higher propagation coefficient, higher growth rate than other species, and higher konjac glucomannan content [2]. At the time of the harvest, konjac tubers have a high moisture content. Since at such moisture content glucomannan may rapidly degrade, it is necessary to dry the corms as soon as possible after harvest. Therefore, in the course of its short shelf period, loss in quality and deterioration in physical appearance is possible.

Drying is one of the oldest and essential operations in many processing industries such as chemical, food, agriculture, biotechnology, pharmaceutical, *etc*. [3, 4]. The most widely applied drying technology is the thermal drying, which involves three different heat transfer mechanisms: conduction, convection, and radiation [5]. During thermal drying process, heat is added to increase the vapour pressure of the moisture within the substances in order to enhance moisture migration and also to substantially decrease the relative humidity of the drying air to increase its moisture carrying capacity [6].

Fluidized bed drying is one of the hot-air drying processes being used for drying of agricultural material in Thailand due to high heat and mass transfer rates between the hot-air and the raw material. This, consequently, induces simultaneously the drying and the inactivation of some undesirable substance in biological materials faster than the conventional hot-air drying. An example of such undesirable substance is the trypsin inhibitor in soybeans. By decreasing its content to an acceptable level the soybeans are fit to be used in food and feed industry in Thailand [7].

Recent study [8] on drying of elephant foot yam using microwave drying reported the drying time, drying rate, kinetic rate constant, effective moisture diffusivity. However, no detailed studies are found in literature on drying kinetics of konjac corm in a fluidized bed dryer. Therefore, the objectives of present investigation are:

– to study the effect of temperature, particle size and bed height on drying kinetics of konjac,
– to select the best model among several thin layers drying models to describe the moisture removal behaviour during fluidized bed drying of konjac, and
– to compute effective moisture diffusivity and the activation energy.

Materials and methods

Samples preparation

Konjac corms were purchased from a processing plant in Chiang Rai, northern Thailand. Corms were washed in running tap water to remove adhering soil and then stored in a refrigerator at 4±1 °C until taken for further processing. Samples of diced konjac (50 g) were dried in hot air oven at 105 °C for 24 hours following the AOAC 1990 method to determine the initial moisture content. The konjac corms were cut into 10 mm cubes using a dicer (GZZT Model MH003 China).

Drying procedure

The drying of konjac dices was investigated using a laboratory scale fluidised bed dryer developed in the Thermal Processing Research Laboratory Faculty of Engineering, Mahasarakham University, Thailand, fig. 1. It consisted of a centrifugal fan with three phase electrical motor of 0.5 hp (298.3 W) with an air heating unit installed behind fan with six electrical heating elements (9 kW). The drying chamber was of an acrylic column with 100 mm diameter and 1000 mm height, respectively. A digital temperature controller with ±0.1 °C accuracy (Model YL-8N, Electric Instrument Styilong Co., Ltd., Guangdong, China) was used to control the inlet air temperature. An inverter with ±0.1 Hz accuracy (TECO FM 5, made in Taiwan) was used to control the inlet air velocity. A digital thermometer with an accuracy of ±0.1 °C (Lutron TM-903, made in Taiwan) and type *k* thermocouple sensor was used.

During each drying experiment, a single layer of konjac dices of about 100±0.5 g was placed in the drying chamber. The moisture loss was periodically recorded by taking out the acrylic column and weighing it on a digital balance (Want, Taiwan) having the accuracy of ±0.01 g. For each drying condition, three replicates were used. During all experiments weighing of drying samples was carried out in less than 10 seconds.

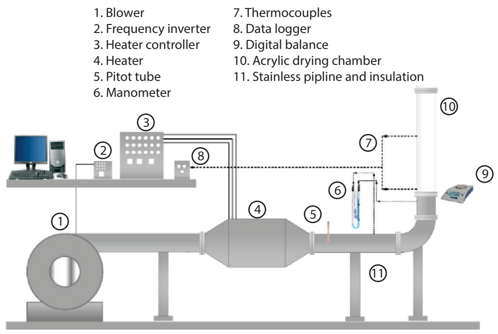

Figure 1. Schematic diagram of the experimental fluidized bed dryer

Mathematical modelling of drying curve

The experimental drying data are presented in terms of reduction in moisture ratio (MR) with drying time. The MR curve displays the drying behaviour of the product over time. It shows the effect of drying temperature on the drying rate in terms of changes of MR was calculated as described in [9-13]:

$$MR = \frac{M_t - M_e}{M_0 - M_e} \tag{1}$$

where M_t, M_0, and M_e (kg water/kg dry matter) are moisture content at any drying time initial and equilibrium moisture content, respectively. As the values of M_e are relatively small compared to those of M_t or M_0, the error involved in the simplification is negligible [9, 10], thus MR was calculated:

$$MR = \frac{M_t}{M_0} \tag{2}$$

For drying model selection, drying curves were fitted to six well known thin layer drying models which are given in tab. 1. The best of fit was determined using three parameters: the highest values for coefficient of determination, R^2, and the lowest, χ^2, root mean square error (RMSE), and reduced sum square errors (SSE) calculated using eqs. (3)-(6), respectively. The statistical analyses were carried out using MINITAB software.

Table 1. Mathematical models applied to drying curves

Model No.	Model name	Model equation	References
1	Newton	$MR = \exp(-kt)$	[11-14]
2	Page	$MR = \exp(-kt^n)$	[13-16]
3	Modified page	$MR = \exp(-kt)^n$	[14, 17, 18]
4	Henderson and Pabis	$MR = a\exp(-kt)$	[11-13, 16]
5	Logarithmic	$MR = a\exp(-kt) + c$	[11, 14, 15]
6	Two term	$MR = a\exp(-kt) + b\exp(-nt)$	[11, 14-16]

$$R^2 = 1 - \left[\frac{\sum_{i=1}^{n} \left(MR_{\exp,i} - MR_{\text{pre},i} \right)^2}{\sum_{i=1}^{n} \left(\overline{MR}_{\text{pre}} - MR_{\exp,i} \right)^2} \right] \tag{3}$$

$$\chi^2 = \sum_{i=1}^{n} \left(MR_{\exp,i} - MR_{\text{pre},i} \right)^2 \tag{4}$$

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

$$SSE = \sum_{i=1}^{n} \left(MR_{\exp,i} - MR_{\text{pre},i} \right)^2 \tag{6}$$

where $MR_{\exp,i}$ is the i^{th} experimental MR, $MR_{\text{pre},i}$ – the i^{th} predicted MR, and n – the number of observations.

Calculation of effective moisture diffusivity

Diffusivity is a very important parameter when studying the moisture migration or mass transfer from the material being dried to drying medium when drying occurs in falling rate period. So there are many assumptions to be taken into account prior to calculation of diffusivity. Falling rate is the most important period of drying which a large amount of moisture is removed. It is necessary to calculate the diffusivity to characterise the drying rate or rate of moisture removal from product when drying takes place in falling rate period. Therefore, during falling rate period, effective diffusion coefficient is generally used to describe the rate of drying. Fick's second law has been used for the description of transport phenomenon of moisture during falling rate period. It could be expressed:

$$\frac{\partial M}{\partial t} = D_{\text{eff}} \frac{\partial^2 M}{\partial z^2} \tag{7}$$

where D_{eff} is the effective moisture diffusivity representing the conductive term of all moisture transfer mechanisms. This parameter is usually determined from experimental drying curves. The solution of Fick's second law in cubic geometry, with the assumptions of moisture migration being by diffusion, unidimensional moisture movement, negligible shrinkage, constant diffusion coefficients and constant temperature [19-21]:

$$MR = \left(\frac{8}{\pi} \right)^3 \sum_{n=0}^{\infty} \left[\frac{1}{(2n+1)^2} \right]^3 \exp\left[-\frac{(2n+1)^2 3\pi^2 D_{\text{eff}} t}{L^2} \right] \tag{8}$$

where D_{eff} [m^2s^{-1}] is the effective diffusivity coefficient, L [m] – the thickness of the cube, and n – the positive integer.

For long drying period, eq. (8) can be further simplified to only the first term of the series:

$$MR = \left(\frac{8}{\pi^2} \right)^3 \exp\left(-\frac{3\pi^2 D_{\text{eff}} t}{L^2} \right) \tag{9}$$

Equation (9) could be further simplified to a straight line equation:

$$\ln(MR) = \ln\left(\frac{8}{\pi^2}\right)^3 - \left(\frac{3\pi^2 D_{\text{eff}} t}{L^2}\right) \tag{10}$$

To determine the effective diffusivity coefficient, D_{eff}, first the slope of the relationships between ln(*MR*) and time eq. (10) is computed, the effect of temp to D_{eff} is then calculated:

$$D_{\text{eff}} = D_0 \exp\left(-\frac{E_{\text{a}}}{\text{R}T_{\text{abs}}}\right) \tag{11}$$

where D_0 [m^{2}s^{-1}] is the pre-exponential factor of the Arrhenius equation, E_{a} [kJmol^{-1}] – the activation energy, R [kJmol^{-1}K^{-1}] – the universal gas constant, and T_{abs} [K] is the absolute temperature. By taking the natural logarithm of both sides, the aforementioned exponential form of Arrhenius can be transformed into a linear logarithmic form, eq. (12). Consequently, E_{a} can be calculated:

$$\ln D_{\text{eff}} = \ln D_0 - \frac{E_{\text{a}}}{\text{R}T_{\text{abs}}} \tag{12}$$

Results and discussion

Drying curve and mathematical modelling

Drying curves of thin layer konjac dices are shown in figs. 2 and 3 for different temperatures, bed heights and cube thickness. Drying rate has increased for all bed heights with increasing temperature and decreasing thickness. Hence the maximum drying time was at 50 °C, 60 mm bed height and 15 mm cube thickness whereas the minimum drying time was at 70 °C, 30 mm bed height and 6 mm cube thickness, respectively. Drying times for different dice thickness and bed height are shown in figs. 4 and 5. The surface temperature of konjac dices is increasing very fast, causing the vapour pressure in product to increase. This results in rapid drying of the product. The drying rates were higher in the beginning of the drying process, *i. e.* during the constant drying rate period and gradually decreased as the drying process entered the falling drying rate period. This was because more heat energy is absorbed by the water at the product surface initially, resulting in faster drying, and with the product surface drying out, heat penetration though the dried layer decreased thus reducing the drying rates. The drying rates are directly related to the amount of heat energy revealed by increased temperature. The other conditions remaining the same increased temperature results in reduction of the drying time [22].

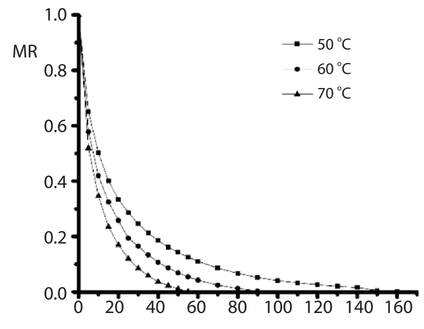

Figure 2. Drying curves of konjac dice at various *T*, 60 mm bed height, 6 mm dice thickness

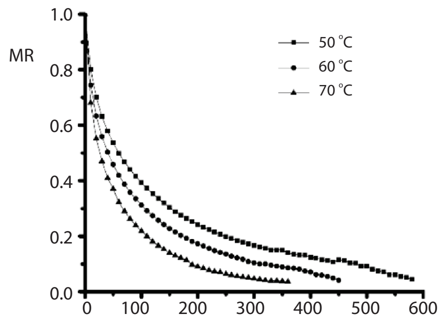

Figure 3. Drying curves of konjac dices at various *T*, 60 mm bed height, 15 mm dice thickness

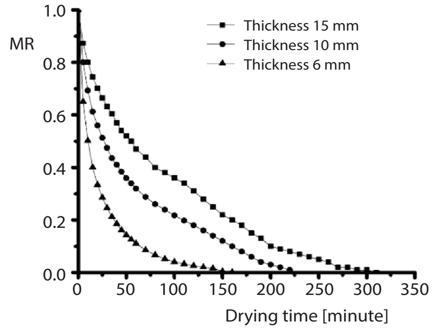

Figure 4. Drying curves of konjac dices of different thickness, 30 mm bed height, *T* = 50 °C

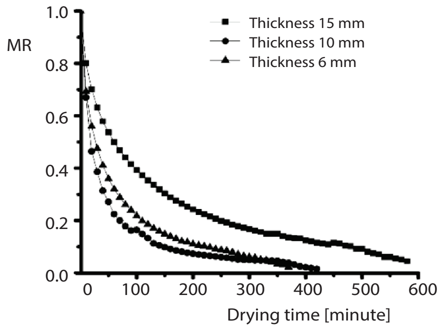

Figure 5. Drying curve of konjac dice of different thickness, 60 mm bed height, *T* = 50 °C

The MR against drying time for the experimental data at various air temperatures was fitted to the Newton, Page's, Modified Page's, Henderson and Pabis, Logarithm, and two-term drying models available in literature. The results of such fitting of the experimental data for the samples dried at 50 °C, 60 °C, and 70 °C are displayed in tab. 2, which shows the values

Table 2. Statistical analysis of drying model fitting for different temperatures, bed heights and dice thicknesses

T [°C]	Bed height [mm]	Thickness [mm]	Newton				Page				Modified page			
			Statistical				Statistical				Statistical			
			R^2	χ^2	RMS*E*	SSE	R^2	χ^2	RMSE	SSE	R^2	χ^2	RMSE	SSE
50	30	6	0.9518	0.0030	0.0546	0.0627	0.9995	0.0000	0.0053	0.0006	0.9995	0.0000	0.0053	0.0006
60	30	6	0.9668	0.0025	0.0497	0.0345	0.9990	0.0000	0.0023	0.0001	0.9990	0.0001	0.0084	0.0010
70	30	6	0.9859	0.0013	0.0363	0.0132	0.9988	0.0001	0.0100	0.0010	0.9988	0.0001	0.0100	0.0010
50	30	10	0.9262	0.0048	0.0694	0.1348	0.9861	0.0011	0.0333	0.0399	0.9915	0.0006	0.0236	0.0156
60	30	10	0.9537	0.0031	0.0555	0.0740	0.9933	0.0005	0.0221	0.0151	0.9966	0.0002	0.0151	0.0055
70	30	10	0.9468	0.0034	0.0579	0.0737	0.9962	0.0003	0.0160	0.0074	0.9966	0.0002	0.0146	0.0047
50	30	5	0.9712	0.0023	0.0479	0.0826	0.9861	0.0011	0.0333	0.0399	0.9861	0.0011	0.0333	0.0399
60	30	15	0.9611	0.0028	0.0531	0.0875	0.9933	0.0005	0.0221	0.0151	0.9933	0.0005	0.0221	0.0151
70	30	15	0.9481	0.0035	0.0588	0.1004	0.9962	0.0003	0.0160	0.0074	0.9962	0.0003	0.0160	0.0074
			0.9568	0.0030	0.0537	0.0737	0.9943	0.0004	0.0178	0.0141	0.9953	0.0003	0.0165	0.0101
50	60	6	0.8675	0.0064	0.0800	0.1599	0.9990	0.0001	0.0071	0.0013	0.9990	0.0001	0.0071	0.0013
60	60	6	0.8166	0.0091	0.0952	0.1812	0.9930	0.0003	0.0186	0.0069	0.9930	0.0003	0.0186	0.0069
70	60	6	0.9721	0.0022	0.0470	0.0265	0.9993	0.0001	0.0076	0.0007	0.9993	0.0001	0.0076	0.0007
50	60	10	0.8876	0.0046	0.0677	0.1512	0.9924	0.0003	0.0177	0.0103	0.9924	0.0003	0.0177	0.0103
60	60	10	0.9064	0.0048	0.0691	0.1098	0.9979	0.0001	0.0105	0.0025	0.9979	0.0001	0.0105	0.0025
70	60	10	0.9030	0.0058	0.0759	0.0979	0.9962	0.0002	0.0151	0.0039	0.9962	0.0002	0.0151	0.0039
50	60	5	0.8427	0.0066	0.0813	0.2315	0.9998	0.0000	0.0032	0.0004	0.9998	0.0000	0.0032	0.0004
60	60	15	0.8536	0.0064	0.0799	0.2234	0.9999	0.0000	0.0018	0.0001	0.9999	0.0000	0.0018	0.0001
70	60	15	0.9028	0.0043	0.0658	0.1516	0.9997	0.0000	0.0037	0.0005	0.9997	0.0000	0.0037	0.0005
			0.8836	0.0056	0.0735	0.1481	0.9974	0.0001	0.0095	0.0029	0.9974	0.0001	0.0095	0.0029

→

Table 2. (continuation)

T [°C]	Bed height [mm]	Thickness [mm]	Henderson and Pabis				Logarithmic				Two term			
			Statistical				Statistical				Statistical			
			R^2	χ^2	RMSE	SSE	R^2	χ^2	RMSE	SSE	R^2	χ^2	RMSE	SSE
50	30	6	0.9656	0.0020	0.0451	0.0427	0.9752	0.0014	0.0374	0.0294	0.9997	0.0000	0.0042	0.0004
60	30	6	0.9727	0.0019	0.0435	0.0266	0.9804	0.0013	0.0356	0.0177	0.9997	0.0000	0.0043	0.0003
70	30	6	0.9865	0.0011	0.0339	0.0115	0.9890	0.0008	0.0291	0.0084	0.9996	0.0000	0.0054	0.0003
50	30	10	0.9668	0.0022	0.0465	0.0607	0.9713	0.0019	0.0433	0.0524	0.9956	0.0003	0.0169	0.0080
60	30	10	0.9773	0.0015	0.0388	0.0362	0.9814	0.0012	0.0352	0.0297	0.9986	0.0001	0.0095	0.0022
70	30	10	0.9688	0.0020	0.0443	0.0432	0.9777	0.0014	0.0374	0.0308	0.9961	0.0002	0.0157	0.0054
50	30	5	0.9873	0.0010	0.0319	0.0366	0.9888	0.0009	0.0299	0.0322	0.9873	0.0010	0.0319	0.0366
60	30	15	0.9849	0.0011	0.0331	0.0339	0.9855	0.0011	0.0325	0.0327	0.9975	0.0002	0.0134	0.0056
70	30	15	0.9781	0.0015	0.0383	0.0425	0.9819	0.0012	0.0347	0.0350	0.9989	0.0001	0.0084	0.0021
			0.9764	0.0016	0.0395	0.0371	0.9812	0.0012	0.0350	0.0298	0.9970	0.0002	0.0122	0.0067
50	60	6	0.9245	0.0036	0.0604	0.0911	0.9680	0.0013	0.0356	0.0316	0.9977	0.0001	0.0105	0.0028
60	60	6	0.8780	0.0060	0.0776	0.1205	0.9813	0.0011	0.0336	0.0226	0.9969	0.0002	0.0123	0.0030
70	60	6	0.9760	0.0019	0.0436	0.0229	0.9858	0.0011	0.0336	0.0135	0.9999	0.0000	0.0035	0.0001
50	60	10	0.9121	0.0036	0.0598	0.1182	0.9788	0.0009	0.0294	0.0285	0.9977	0.0001	0.0096	0.0031
60	60	10	0.9321	0.0035	0.0589	0.0797	0.9750	0.0013	0.0357	0.0293	0.9987	0.0001	0.0081	0.0015
70	60	10	0.9267	0.0043	0.0657	0.0734	0.9684	0.0019	0.0432	0.0317	0.9975	0.0001	0.0121	0.0025
50	60	5	0.9415	0.0025	0.0496	0.0862	0.9834	0.0007	0.0263	0.0242	0.9980	0.0001	0.0092	0.0029
60	60	15	0.9380	0.0027	0.0520	0.0946	0.9770	0.0010	0.0317	0.0351	0.9981	0.0001	0.0092	0.0030
70	60	15	0.9474	0.0023	0.0484	0.0821	0.9730	0.0012	0.0347	0.0420	0.9986	0.0001	0.0079	0.0022
			0.9307	0.0034	0.0573	0.0854	0.9767	0.0012	0.0337	0.0287	0.9981	0.0001	0.0092	0.0023

of the estimated constants with their corresponding statistical evaluation parameters R^2, χ^2, RMSE, and SSE characterizing each fitting. From the results obtained, it is evident that the experimental data fitted well the models used in this study. The R^2 obtained are in the range of 0.88358-0.99812. This means that the six models could satisfactorily describe the hot-air drying of konjac dices. The relatively high values of R^2, low reduced chi square, low RMSE, and SSE indicate a good predicting capacity for the temperature tested over the entire duration of the drying process. Among the six thin-layer drying models tested, the two-term model obtained the highest R^2 values and the lowest χ^2, RMSE, and SSE values. Figures 6 and 7, display the fitting of the experimental and simulated points to the two-term, and modified page's models, respectively. It can be seen from figures that the experimental data are close to the simulated data for both models. In contrast, at the latter stages of drying, the experimental data were further away from the predicted data for Newton, Henderson and Pabis, and Logarithmic models (results not shown here) as indicated by the results of statistical analysis shown in tab. 2.

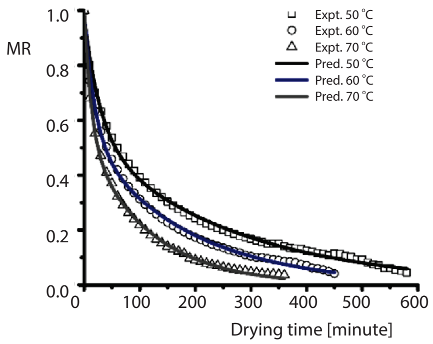

Figure 6. Fitting of experimental data to the modified page's model

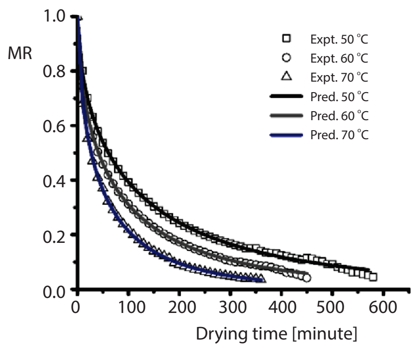

Figure 7. Fitting of experimental data to two-term model

Moisture diffusivity and activation energy

The effective moisture diffusivity of konjac dice was determined using the drying data. Non-linear regression technique was used to estimate the effective moisture diffusivity, D_{eff}, of Fick'sdiffusion equation, eq. (10). The variation of ln(MR) against drying time for the konjac dices dried at 50 °C, 60 °C, and 70 °C is shown in fig. 8. The results of the effective moisture diffusivity coefficient, D_{eff}, of konjac dices ranged from $9.60526 \cdot 10^{-9}$-$1.2006 \cdot 10^{-7}$ m^2/s. For dried samples at 50 °C, 60 °C, and 70 °C, 30-60 mm bed height, and 6, 10, and 15 mm dice thickness, respectively. The D_{eff} values increased significantly with increasing temperature, increasing thickness and decreasing bed height as shown in tab. 3.

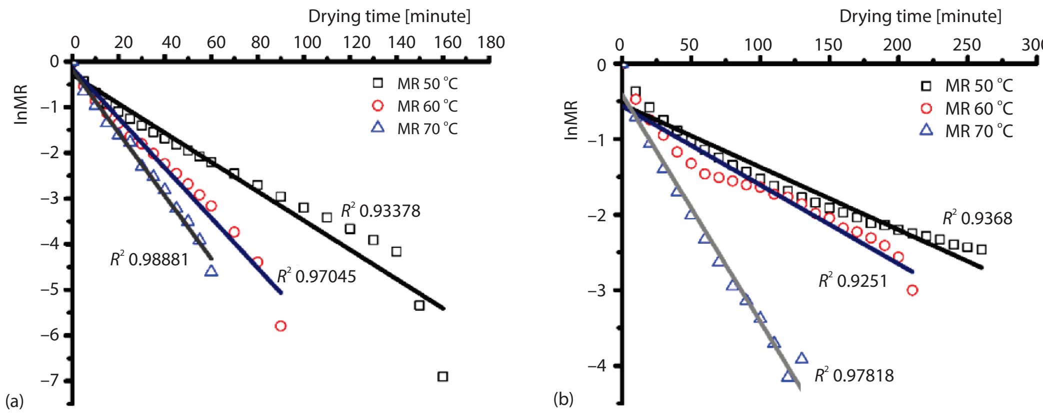

Figure 8. Variation of ln(MR) *vs.* drying time for different drying air temperatures; (a) 30 mm bed height, 6 mm dice thickness, (b) 60 mm bed height, 15 mm dice thickness

The result of major factors (bed height, drying air temperature, and thickness) on the effective moisture diffusivity is shown in fig. 9, called main effects plot for D_{eff}. Considering the graphs in fig. 9, it appears that bed height has negative effect on D_{eff}, *i. e.* as bed height increases from 30-60 mm there is a decrease in D_{eff}. In contrast, the temperature has a positive effect, *i. e.*

When temperature increases, the D_{eff} increases. Similarly, if the dice thickness increases, the D_{eff} increases *vice versa* bed height increases D_{eff}.

Table 3. Effective diffusivity coefficient values for different bed heights, dice thicknesses, and drying air temperatures

Bed height [mm]	Thickness [mm]	T [°C]	D_{eff} [m^{2}s^{-1}]	E_a [Kgmol^{-1}]
30	6	50	$3.89 \cdot 10^{-8}$	33.86949
		60	$6.65 \cdot 10^{-8}$	
		70	$8.09 \cdot 10^{-8}$	
	10	50	$5.64 \cdot 10^{-8}$	16.7514
		60	$7.19 \cdot 10^{-8}$	
		70	$8.1 \cdot 10^{-8}$	
	15	50	$9.95 \cdot 10^{-8}$	8.650095
		60	$1.11 \cdot 10^{-7}$	
		70	$1.2 \cdot 10^{-7}$	
60	6	50	$9.61 \cdot 10^{-9}$	61.28737
		60	$1.26 \cdot 10^{-8}$	
		70	$3.66 \cdot 10^{-8}$	
	10	50	$2.4 \cdot 10^{-8}$	41.0761
		60	$3.88 \cdot 10^{-8}$	
		70	$5.84 \cdot 10^{-8}$	
	15	50	$3.19 \cdot 10^{-8}$	31.90798
		60	$4.33 \cdot 10^{-8}$	
		70	$6.38 \cdot 10^{-8}$	

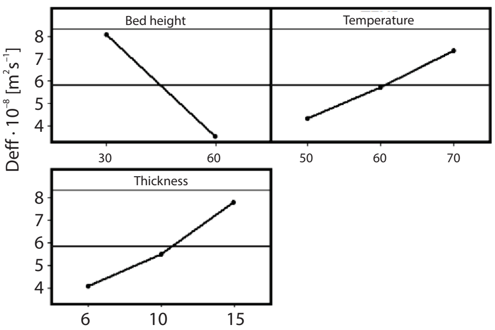

Figure 9. Main effects plot for D_{eff}

The moisture diffusivities values were used in eq. (12) to estimate the activation energy, E_a, for moisture diffusion. Figure 10 shows the influence of high drying air temperature on effective moisture diffusivity. The results of such fitting gave R^2 of 0.88192-0.9926 indicating that the quality of fitting was good. The maximum value of the activation energy for moisture diffusion in the experiments conducted in this study was found to be 61.28 KJ/mol for 60 mm bed height and 6 mm dice thickness. The values of activation energy were found to be higher than those of 8.3143 kJ/mol for tomato [22], 46.80-52.68 kJ/mol for rosy garlic leaves [23], 57.36 kJ/mol for Moroccan rosemary leaves [24], 32.65 kJ/mol for banana slices [25], 13.48-16.50 kJ/mol for sweet potatoes slices [18], and 12.50 kJ/mol for drumstick leaves [26] dried under similar conditions. About the same values were obtained for konjac dices as those of 30.64 kJ/mol for persimmon slices [27], 30.00 kJ/mol for bacon slices [17], and 22.01-30.99 kJ/mol for green peas [28] dried under similar conditions. In general, the activation energy, when drying food and agricultural products, ranges between 12.7-110 kJ/mol [29].

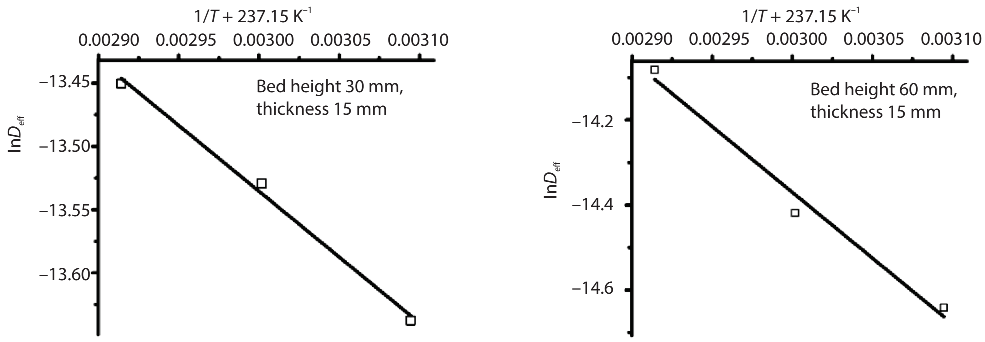

Figure 10. Influence of high drying air temperature on effective moisture diffusivity

Conclusion

The fluidized bed drying of konjac dices was carried out in falling-rate period. This fact indicates that moisture transfer during drying is controlled mainly by internal diffusion. Two-term model showed the best fit for drying kinetics compared with the other empirical models tested. The effects of drying air temperature in the range of 50-70 °C, 30-60 mm bed height and 6 mm, 10 mm, and 15 mm dice thickness of konjac were characterized. The effective diffusivity coefficient increases with air temperature and consequently the drying time decreased. The effective moisture diffusivity values ranged from $9.60526 \cdot 10^{-9}$-$1.2006 \cdot 10^{-7}$m^2/s. The temperature dependence of effective diffusivity coefficients was described adequately by Arrhenius-type equation. The activation energy for moisture diffusion was found to be between 8.65 kJ/mol and 61.28 kJ/mol. This study describes drying behaviour of konjac dices at different bed height and of different thickness in a fluidized bed at high drying air temperatures. The information found in this study can be useful in the design of drying equipment and simulation of the drying process of konjac corms as a source of glucomannan for food and pharmaceutical industry.

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