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Osmotic dehydration of aloe vera cubes and selection of suitable drying model

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Abstract

In the present study, the effect of pretreatments (i.e. osmotic dehydration in 30, 40 and 50ºBrix sugar solution at 30ºC syrup temperature) and drying air temperature (50, 60, 70 and 80ºC) on drying behaviour of aloe vera cubes were investigated. The aloe vera cubes were dried in a laboratory model tray dryer. Drying of aloe vera occurred in falling rate period. Five thin-layer drying models (Exponential, Page, Henderson and Pabis, Logarithmic and Power law) were fitted to the moisture ratio data. Among the drying models investigated, the Page model satisfactory described the drying behavior of aloe vera cubes. During convective dehydration, the average effective moisture diffusivity of un-osmosed and osmosed samples at drying air temperatures ranging from 50 to 80 ºC varied between 2.69 to 4.59 $\times 10^{-09}$ m²/s between 2.93 to 7.99$\times 10^{-09}$ m²/s respectively.

Introduction

Aloe vera (*Aloe barbadensis* Miller), a traditional medicinal plant used in food, pharmaceutical and cosmetic industries (Grindlay and Reynolds, 1986; Koga, 1998). Aloe vera is a tropical and subtropical plant of *Liliaceae* family with turgid green leaves joined at the stem in a rosette pattern. The aloe leaf contains a transparent mucilaginous jelly which is referred to as aloe vera gel. Gel contains 97 - 98 per cent of water and more than 60 per cent of the dry matter is made up of polysaccharides (Femenia *et al*., 1999; Mcanalley, 1993). The gel is a colourless, odourless, hydrocolloid with several natural beneficial substances. Reports credit that aloe has ant tumor (Loadman and Calabrese, 2001), ant diabetic (Beppu *et al*., 1993), and ant tyrosine properties (Yagi *et al.*, 1987) in addition to efficacy in healing wounds and burns (Chithra *et al*., 1998; Somboonwong *et al.*, 2000). The action of aloe gel as a moisturizing agent is still popular concept (Briggs, 1995). Aloe vera gel has got the potential to be used as a food preservative, as a substitute of sulphur dioxide in preserving fruit and vegetables. It contains a number of nutrients such as vitamins, fatty acids, amino acids, sugars, minerals, enzymes therefore dried powder can be used in formulations as a functional ingredient for health benefits. Aloe leaf powder, which contains antioxidants, dietary fibre, iron, etc., may find its usage in number of ayurvedic medicines.

Drying is one of the methods of food preservation. The main attribute of this method is the decrease in the water activity in the product by decreasing its water content, inhibiting the development of microorganisms and decreasing spoilage reactions, thus prolonging the shelf life of the product. An important advantage of dehydrated products is that their costs of packing, storage and transportation are reduced due to the comparatively smaller volume and mass of the dried product (Okos *et al.*, 1992). Furthermore, products with low moisture content can be stored for long periods of time at room temperature (Jarayaman and DasGupta, 1995). The simplest and most economic method for dehydration of food is air-drying; although certain problems such as the considerable shrinkage caused by cell collapse following the loss of water, the poor re-hydration characteristics of dried product and unfavourable changes in colour, texture, flavour and nutritive value may occur. Vega *et al.* (2007) studied the kinetics of the hot-air drying of aloe vera gel and evaluated the influence of temperature on the kinetic parameters for the proposed models. Miranda *et al.* (2009) investigated the effect of air temperature on the physicochemical and nutritional properties and antioxidant capacity of aloe vera gel. Vega-Gálveza *et al*. (2009) studied the effect of temperature on rehydration kinetics of rehydrated aole vera slabs.

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Miranda *et al.* (2010) studied the applicability of the Weibull distribution model to predict the moisture content of aole vera gel dried by hot-air and to evaluate the effects of temperature on the kinetic parameters, structural properties (texture and microstructure), and total polysaccharide content.

To improve air-drying process pre-treatment prior to drying required, osmotic dehydration is one of the most useful pre-treatment for drying of fruits and vegetables (Beaudry, 2001). Osmotic dehydration is the incomplete removal of water from a food product by means of an osmotic agent (usually either sugar or salt solution). The main advantage of this process is its influence on the principal drying method, shortening of the drying process, resulting in lower energy requirements. Considering that heat is not applied in this stage, osmotic dehydration offers higher retention of initial food characteristics, such as colour, aroma, nutritional constituents, and flavour compounds. Sucrose is considered one of the best osmotic substances, especially when the osmotic dehydration is employed before drying. The presence of this sugar on the surface of the dehydrated sample is an obstacle for the contact with oxygen (Lenart, 1996), which reduces the oxidative reactions.

The drying kinetics of food is a complex phenomenon and requires simple representations to predict the drying behaviour, and for optimize the drying parameters. Recently, studies have been done on drying kinetics of fruits and vegetables (Togrul and Pehlivan, 2002; Jain and Pathare, 2004; Doymaz, 2004; Akpinar and Bicer, 2005; Goyal *et al.*, 2006; Revaskar *et al*., 2013). However, work on the effect of pretreatments i.e. osmotic dehydration, on drying kinetics of aloe vera has not yet been reported. The objective of this study was (i) to investigate the influence of pretreatments and drying air temperature in the drying behavior of aloe vera, (ii) to evaluate a suitable thin-layer drying model for describing the drying process, and (iii) to calculate the effective moisture diffusivity.

Materials and Methods

Raw material

Aloe vera (*Aloe barbadensis* Miller) for this investigation was procured from the Herbal Park, Rajasthan College of Agriculture, Mahararana Pratap University of Agriculture and Technology, Udaipur (India). Fresh whole aloe vera leaves of between 30 and 50 cm of length from 3 to 4 year old plants were cut and whole leaves were washed under tap water and placed vertically. The spikes, placed along the margins, were removed before slicing the leaves. The thick epidermis (or skin) was carefully separated from the parenchyma (or gel fillet) using a stainless steel cutter. The fillets were cut into 12.5 × 12.5 × 12.5 mm cubes with the help of sharp stainless steel cutter. A sample was freshly prepared on each day of experiment. The initial moisture content was determined by AOAC methodology no. 934.06 (AOAC, 1990), which was 54.87 kg water/kg dry matter.

Osmotic dehydration

Aloe vera cubes were partially dehydrated using osmotic dehydration technique. The cubes were placed in different containers holding 30, 40 and 50ºBrix of sugar solution at constant temperature (30ºC) for 4 h; and stirring of the solution was done at regular intervals of 15 minutes. Syrup to fruit ratio was kept constant as 5:1. After a period of 4 h, cubes were removed quickly and blotted gently using a tissue paper to remove the surface moisture.

Hot-air-drying

Samples non-treated and pre-treated in osmotic solution (30, 40 and 50ºBrix sugar solution) were dried in a laboratory tray dryer. The dryer consisted of a drying chamber, electric heater, fan and a temperature controller. Experiments were conducted at 50, 60, 70 and 80ºC air temperature and at a constant airflow velocity of 1.5 m/s. After the dryer reached the set conditions, cubes of raw aloe vera samples (150 g) were uniformly spread in each trays and kept in dryer. Moisture loss was recorded in 30 min interval by a digital balance of 0.01 g accuracy. The drying was continued until there was no large variation in the moisture loss. Experiments were replicated three times. A total 16 treatments combination as described in Table 1 was conducted.

Mathematical modelling

Mathematical modelling is essential to predict and simulate the drying behavior. It is also an important tool in dryer's design, contributing to a better understanding of the drying mechanism. The experimental drying data was graphically analyzed in terms of reduction in moisture content and moisture ratio with drying time. Since the moisture ratio curve can better explain the drying behaviour than that of moisture content curve, the moisture ratio values were used to predict the drying model for pre-treated and non-treated samples of aloe vera. To select a suitable model for describing the drying process of aloe vera cubes, drying curves were fitted with five thin-layer drying equations, namely Exponential (Eq. (1)), Page (Eq. (2)), Henderson–Pabis (Eq. (3)), Logarithmic

Table 1. The relationship between drying rate D_R and moisture content M for convective drying of aloe vera cubes [$D_R = aM + b$]

Treatment No.	Temperature of osmotic solution (°C)	Syrup concentration (°Brix)	Drying Temperature (°C)	Drying time (min)	Drying rate constant		R^2	Standard error
					a	*b*		
1	–	–	50	450	0.4738	3.5754	0.9383	2.3860
2	–	–	60	420	0.8824	0.2902	0.9288	0.5491
3	–	–	70	270	0.8323	-0.0704	0.9901	0.1598
4	–	–	80	180	0.8837	-0.1903	0.9758	0.2393
5	30	30	50	300	0.6274	2.7660	0.9663	2.2606
6	30	30	60	270	1.2538	0.1161	0.9805	0.3937
7	30	30	70	210	1.1674	-0.1366	0.9962	0.1372
8	30	30	80	150	1.2655	-0.3716	0.9914	0.1991
9	30	40	50	420	0.7567	4.9527	0.9622	2.8433
10	30	40	60	300	1.5075	0.3098	0.9542	0.7635
11	30	40	70	270	1.4556	-0.0679	0.9893	0.2937
12	30	40	80	180	1.6039	-0.4890	0.9811	0.3760
13	30	50	50	450	0.9428	7.7816	0.9397	4.4968
14	30	50	60	330	1.5801	0.9694	0.8924	1.3929
15	30	50	70	300	1.8369	0.0566	0.9867	0.4332
16	30	50	80	240	2.1177	-0.6625	0.9914	0.3371

(Eq. (4)), Power law (Eq. (5)) (Akpinar and Bicer, 2005; Doymaz, 2004; Togrul and Pehlivan, 2002).

Exponential $MR = \exp(-kt)$ (1)

Page $MR = \exp(-kt^n)$ (2)

Henderson-Pabis $MR = a\exp(-kt)$ (3)

Logarithmic $MR = a + b\ln(t)$ (4)

Power law $MR = At^B$ (5)

where MR is dimensionless moisture ratio; t is the time (s).

The acceptability of the model has been determined by the coefficient of determination (R^2), was one of the main criteria for selecting the best equation. In addition to the coefficient of determination, the goodness of fit was determined by various statistical parameters such as standard errors (SEE), reduced mean square of the deviation χ^2, mean bias error E_{MB} and root mean square error E_{RMS}. For quality fit, R^2 value should be higher close to one and SEE, χ^2, E_{MB} and E_{RMS} values should be lower (Sarsavadia *et al*., 1999; Togrul and Pehlivan, 2002; Demir *et al*., 2004). The above parameters can be calculated as follows:

$$\chi^2 = \frac{\sum_{i=1}^{N}\left(M_{R,\exp,i} - M_{R,pre,i}\right)^2}{N - z} \quad (6)$$

$$E_{MB} = \frac{1}{N}\sum_{i=1}^{N}\left(M_{R,pre,i} - M_{R,\exp,i}\right) \quad (7)$$

$$E_{RMS} = \left[\frac{1}{N}\sum_{i=1}^{N}\left(M_{R,pre,i} - M_{R,\exp,i}\right)^2\right]^{1/2} \quad (8)$$

where $M_{R,\exp,i}$ and $M_{R,pre,i}$ are the experimental and predicted dimensionless moisture ratios, respectively; N is the number of observations; and z is the number of drying constants.

Results and Discussion

Drying behaviour of pre-treated (osmosed) and non-treated aloe vera cubes

Drying air temperature had an important effect on drying (Figures. 1-4). At the higher temperature, due to the quick removal of moisture, the drying time was less. Similar observations have been reported for drying of aloe vera (Vega *et al*., 2007; Miranda *et al*., 2009), garlic slices (Madamba *et al*., 1996), onion slices (Sarsavadia *et al.*, 1999) and egg plants (Akpinar and Bicer, 2005). It is evident that pre-treatment had effect on moisture movement from the samples. It also observed from Table 1, as the sugar concentration (ºBrix) increase, drying time increased, at same drying temperature, this could be due to the resistance offered to water removal by the solute gained during osmotic pre-treatment, which is accordance to Kaleemullah *et al.* (2002), Lenart and Cerkowniak (1996) and Singh and Gupta (2007) also reported that, even a simple immersion of raw materials into an osmotic solution, caused a substantial decrease of water removal rates in convective dehydration. Pre-treatment of fruits in sugar solutions usually reduces the convective drying rates (Rahman and Lamb, 1991; Karathanos *et al.*, 1995; Simal *et al.*, 1997).

The effect pre-treatment on drying rate of aloe vera cubes was also evaluated. The drying rates were calculated from the drying data by estimating the change in moisture content, which occurred in each consecutive time interval and was expressed as g H_2/g dry matter min^{-1}. The drying rates were higher at the beginning of the drying process and later decreased with decreasing moisture content for non-treated and osmotically pre-treated samples under all the conditions of convective dehydration. The

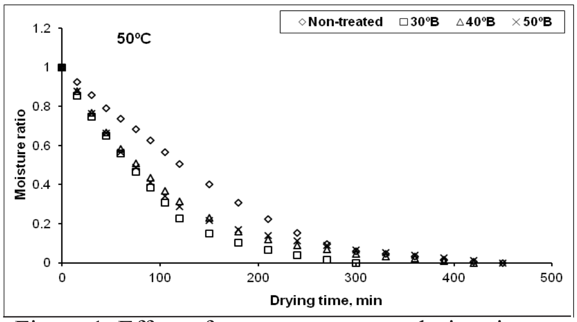

Figure 1. Effect of pre-treatments on drying time at drying air temperature of 50ºC

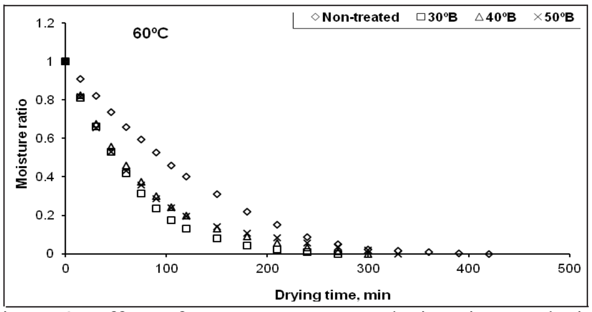

Figure 2. Effect of pre-treatments on drying time at drying air temperature of 60ºC

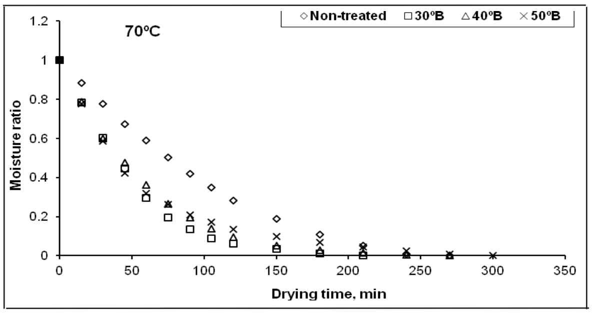

Figure 3. Effect of pre-treatments on drying time at drying air temperature of 70ºC

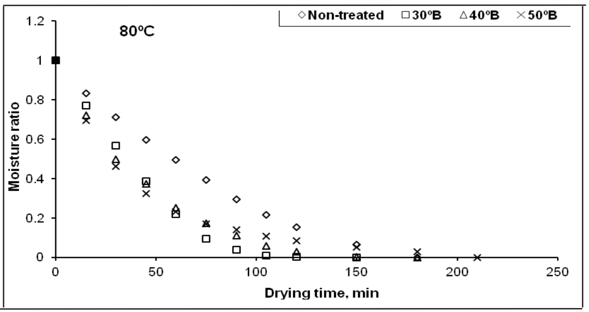

Figure 4. Effect of pre-treatments on drying time at drying air temperature of 80ºC

Table 2. Values of model constants and statistical parameters

Model	Treatment Numbers	Statistical parameters				
		R^2	SEE	$\chi^2\times10^{-3}$	$E_{MB}\times10^{-3}$	E_{RMS}
Exponential	1	0.9594	0.3116	1.276018	1.208860	0.034768
	2	0.9350	0.4967	1.537335	1.451928	0.038104
	3	0.9092	0.4805	2.055126	1.897040	0.043555
	4	0.9630	0.1737	0.939335	0.845401	0.029075
	5	0.9809	0.1829	0.546548	0.507508	0.022527
	6	0.9884	0.1659	0.341311	0.315057	0.017749
	7	0.9953	0.0993	0.356019	0.323653	0.017990
	8	0.9118	0.6814	4.457151	3.961912	0.062943
	9	0.9881	0.1565	0.102360	0.096673	0.009832
	10	0.9815	0.1847	0.091458	0.084925	0.009215
	11	0.9885	0.1837	0.231722	0.213898	0.014625
	12	0.8752	0.7418	1.598578	1.438720	0.037930
	13	0.9901	0.1309	0.546548	0.507508	0.022527
	14	0.9911	0.1158	0.058013	0.054145	0.007358
	15	0.9753	0.2295	0.055845	0.051856	0.007201
	16	0.9921	0.1210	0.227392	0.208442	0.014437
Page	1	0.9859	0.1489	0.005292	0.004630	0.002151
	2	0.9859	0.1509	0.008757	0.007589	0.002755
	3	0.9811	0.1631	0.018649	0.015780	0.003972
	4	0.9856	0.1109	0.025375	0.020761	0.004556
	5	0.9923	0.0902	0.027786	0.023817	0.004880
	6	0.9975	0.0491	0.007538	0.006378	0.002525
	7	0.9977	0.0459	0.012831	0.010498	0.003240
	8	0.9809	0.1624	0.145650	0.113284	0.010643
	9	0.9985	0.0902	0.002025	0.001799	0.001341
	10	0.9969	0.0491	0.003187	0.002732	0.001652
	11	0.9978	0.0459	0.006696	0.005666	0.002380
	12	0.9810	0.1624	0.080077	0.064062	0.008003
	13	0.9965	0.0902	0.012265	0.010974	0.003310
	14	0.9967	0.0491	0.007720	0.006691	0.002590
	15	0.9914	0.0459	0.019793	0.016965	0.004120
	16	0.9945	0.1624	0.017429	0.014524	0.003810
Henderson & Pabis	1	0.9594	0.3116	1.648611	1.475073	0.038406
	2	0.9350	0.4967	3.562936	3.167054	0.056276
	3	0.9666	0.1730	0.605332	0.512204	0.022631
	4	0.9630	0.1737	0.883563	0.706850	0.026585
	5	0.9809	0.1829	0.628024	0.538306	0.023201
	6	0.9884	0.1659	0.523298	0.442791	0.021042
	7	0.9953	0.0993	0.365802	0.29929	0.017300
	8	0.9451	0.3021	2.662251	2.070639	0.045504
	9	0.9881	0.1564	0.110101	0.097867	0.009892
	10	0.9815	0.1847	0.160592	0.137650	0.011732
	11	0.9885	0.1837	0.435331	0.368357	0.019192
	12	0.9799	0.1766	0.509820	0.407856	0.020195
	13	0.9900	0.1309	0.013789	0.012338	0.003512
	14	0.9911	0.1158	0.041726	0.036162	0.006013
	15	0.9753	0.2293	0.041119	0.035245	0.005936
	16	0.9921	0.1209	0.219590	0.182991	0.013527
Logarithmic	1	0.9457	0.0779	3.482837	3.116223	0.055823
	2	0.9686	0.0572	3.221048	2.863153	0.053508
	3	0.9662	0.0557	6.160226	5.212499	0.072197
	4	0.9605	0.0557	9.645670	7.716536	0.087843
	5	0.9739	0.0479	0.162104	0.138947	0.011788
	6	0.9821	0.0374	0.106103	0.089779	0.009475
	7	0.9749	0.0443	0.174297	0.142607	0.011941
	8	0.9822	0.0415	0.184085	0.143177	0.011966
	9	0.9839	0.0371	0.071747	0.063775	0.007985
	10	0.9910	0.0258	0.043563	0.037340	0.006110
	11	0.9773	0.0403	0.113725	0.096228	0.009809
	12	0.9935	0.0209	0.038285	0.030628	0.005534
	13	0.9839	0.0358	0.063409	0.056735	0.007532
	14	0.9883	0.0279	0.047890	0.041505	0.006442
	15	0.9753	0.0383	0.096258	0.082507	0.009083
	16	0.9647	0.0417	0.130110	0.108425	0.010412
Power law	1	0.7153	0.8243	26.38204	23.60549	0.153639
	2	0.6819	1.1011	58.75002	52.22222	0.2285218
	3	0.6393	0.8720	19.00841	16.08355	0.1268209
	4	0.7738	0.4181	4.133498	3.306798	0.0575047
	5	0.7806	0.6121	12.03973	10.31977	0.101586
	6	0.8057	0.6646	14.34361	12.13690	0.110167
	7	0.8623	0.5164	8.378008	6.854734	0.082793
	8	0.7678	0.8292	14.51078	11.28616	0.106236
	9	0.8059	0.6225	12.36270	10.98906	0.104828
	10	0.7974	0.5978	7.430728	6.369195	0.079807
	11	0.8137	0.7225	17.26096	14.60543	0.120853
	12	0.8385	0.4725	3.033119	2.426495	0.049259
	13	0.8423	0.5066	6.842399	6.122146	0.078244
	14	0.8589	0.4429	4.333728	3.755897	0.061285
	15	0.8201	0.5958	5.966931	5.114512	0.071516
	16	0.8837	0.4330	2.680009	2.233341	0.047258

reason of reduction of drying rate might be due to reduction in porosity of the material due to shrinkage with the advancement of drying process, and this shrinkage increased the resistance to movement of water leading to further fall in drying rates. These shows agreement with the results reported by other researcher for aloe vera (Simal *et al*., 2000; Miranda *et al*., 2009). Continuous decrease in moisture ratio indicates that, diffusion has governed the internal mass transfer. This is in agreement with the results of study on onions (Mazza and Lemaguer, 1980), lettuce and cauliflower leaves (Lopez *et al*., 2000) and figs (Piga *et al*., 2004). Aloe vera cubes did not exhibit a constant rate period of drying. The absence

Table 3. Effective moisture diffusivity for aloe vera cubes

Treatment No.	Temperature of osmotic solution (ºC)	Syrup concentration (ºBrix)	Temperature of drying (ºC)	Diffusivity (m^2/s)	R^2	Standard error
1	–	–	50	2.69×10^{-09}	0.9732	0.2170
2	–	–	60	3.09×10^{-09}	0.9587	0.2805
3	–	–	70	3.56×10^{-09}	0.9666	0.1730
4	–	–	80	4.59×10^{-09}	0.9630	0.1737
5	30	30	50	3.88×10^{-09}	0.9809	0.1829
6	30	30	60	5.12×10^{-09}	0.9884	0.1659
7	30	30	70	6.39×10^{-09}	0.9953	0.0993
8	30	30	80	7.99×10^{-09}	0.9491	0.2200
9	30	40	50	2.93×10^{-09}	0.9881	0.1564
10	30	40	60	3.98×10^{-09}	0.9815	0.1847
11	30	40	70	5.33×10^{-09}	0.9976	0.0677
12	30	40	80	6.86×10^{-09}	0.9881	0.1132
13	30	50	50	2.48×10^{-09}	0.9901	0.1309
14	30	50	60	3.25×10^{-09}	0.9911	0.1158
15	30	50	70	4.27×10^{-09}	0.9753	0.2293
16	30	50	80	5.17×10^{-09}	0.9921	0.1209

of a constant drying rate period may be due to the thin layer of product that did not provide a constant supply of water for an applied period of time. The drying occurred throughout under falling rate of drying period. Similar results have been reported for the drying studies on plum (Ibitwar *et al*., 2008) and apricots (Doymaz, 2004). Table 1 illustrates the linear relationship between drying rate and moisture content obtained from linear regression analysis. The values for the coefficient of determination R^2 were in the range of 0.8924 - 0.9962. These results show that the thin layer drying of aloe vera cubes occurs entirely in the falling rate period.

Mathematical modeling of drying curves

The moisture ratio data of pre-treated and non-treated aloe vera cubes dried at various temperatures were fitted into the different thin-layer drying models. The adequacy of the model can be based on a value of the coefficient of determination R^2, which should be close to one, and low value of (SEE), χ^2, E_{MB} and E_{RMS}, are presented in Table 2. It can be observed from Table 2 that the Page model has the highest value R^2 of (0.9809 - 0.9985) and lower values of SEE (0.0459 - 0.1631), χ^2 (0.002024 - 0.1456503 × 10^{-3}), E_{MB} (0.001799 - 0.11328 × 10^{-3}) and E_{RMS} (0.00134 - 0.01064) for all drying treatment. Therefore, the Page model may be assumed to represent the thin-layer drying behaviour of aloe vera cubes. Similar results were reported for bay leaves (Demir *et al*., 2004) and raw mango slices (Goyal *et al*., 2006).

Figure 5 suggest the experimental moisture ratios fitted with the page model at various air temperature for aloe vera samples, also Figure 6 shows a comparison between both observed and predicted moisture values obtained using the Page model, which gave the best fit for the entire aloe vera drying process. This means that the model has very high performance for describing the characteristics of drying curves.

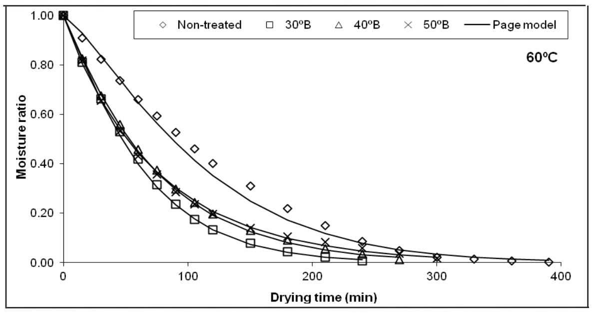

Figure 5. Experimental moisture ratio versus drying time fitted with the Page model at drying air temperature of 60ºC

Effective moisture diffusivity

The continuous decrease in moisture ratio with increase in drying time shows that the results can be interpreted by using Fick's diffusion model. The solution of Fick's diffusion equation for particles with slab geometry, with the assumption that moisture migration was caused by diffusion, negligible shrinkage, constant diffusion coefficients and temperature was as follows (Crank, 1975): For infinite plate shape (aloe vera cubes was considered to be infinite plate shape)

$$M_R = \frac{M - M_e}{M_0 - M_e} = \frac{8}{\pi^2}\sum_{n=1}^{\infty}\frac{1}{(2n+1)^2}\exp\left[\frac{-(2n+1)^2\pi^2 D_{eff} t}{4H^2}\right] \quad (9)$$

For long drying periods, Eqn (9) can be further simplified to only the first term of the series.

$$\ln\left(\frac{M - M_e}{M_0 - M_e}\right) = \ln\frac{8}{\pi^2} - \left(\frac{\pi^2 D_{eff} t}{4H^2}\right) \quad (10)$$

where M_R is the dimensionless moisture ratio, M the moisture content at any time (kg water/kg dry matter), M_0 the initial moisture content (kg water/kg dry matter), M_e the equilibrium moisture content (kg water/kg dry matter), D_{eff} the effective diffusivity (m^2/s), H the half thickness of slab in sample (m), n the positive integer, t the time (s).

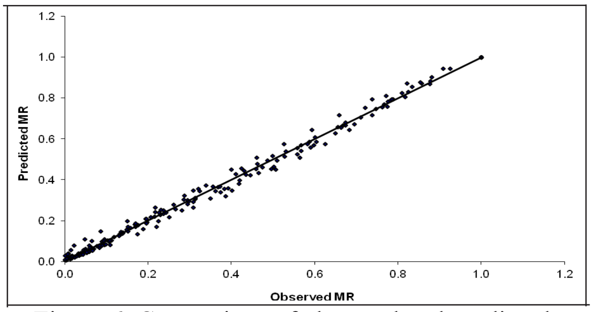

Figure 6. Comparison of observed and predicted dimensionless moisture ratio values by Page model

A general form of Eq. (10) could be written in semi-logarithmic form, as follows.

$$\ln(M_R) = A - Bt \qquad (11)$$

The effective diffusivity is typically calculated by plotting experimental drying data in terms of ln (M_R) versus drying time. From Eqn (11), a plot of ln (M_R) versus the drying time gives a straight line with a slope of:

$$Slope = \frac{\pi^2 D_{\text{eff}}}{4H^2} \qquad (12)$$

The moisture diffusivity value of food material was affected by moisture content as well as temperature. Drying at higher temperature gave highest D_{eff} values. At lower level of moisture content the diffusivity is less than that of high moisture content. The moisture diffusivity varied in the range of 2.69 to 4.59 $\times 10^{-09}$ m²/s and 2.93 to 7.99$\times 10^{-09}$ m²/s for non-treated and pre-treated aloe vera samples depending on the drying air temperature (Table 3). Table 3 indicates that the effective moisture diffusivity increases with drying air temperature in both non-treated and pre-treated samples might be because of increase in the vapour pressure inside the aloe vera cubes. It is in accordance of the results reported by Rahman and Lamb (1991) and Pokharkar and Prasad (1998). These values are within the general range of 10^{-08} to 10^{-12} m²/s for drying of food materials (McMinn and Magee, 1999). Table 3 also indicates the effective moisture diffusivity during convective dehydration of osmosed samples was higher than untreated samples. The increase of effective moisture diffusivity with osmotic pretreatment can be due to loosening of the surface cellular structure and leaching of some soluble components of the external cell layers of arils during soaking in osmotic solution of sugar. Similar results have been reported in apricot cubes (Riva *et al*., 2005), in melons (Rodrigues and Fernandes, 2007) and in pomegranate arils (Mundada *et al.*, 2010).

Conclusions

The effect of temperature and pre-treatment on drying behaviour of aloe vera cubes in tray dryer was investigated in this study. Increase in drying air temperature from 50 to 80ºC decreased the drying time from 450 to 180 min for both pre-treated and non-treated samples. The entire drying process occurred in falling rate period and constant rate period was not observed. Five thin-layer drying equations were investigated for their suitability to describe the drying behaviour of aloe vera cubes. The Page model shows the best fit with high values for the coefficient of determination (0.9809 - 0.9985) and low SEES, χ^2, E_{MB} and E_{RMS} values. Osmotic pretreatment also results in increases effective moisture diffusivity during convective dehydration.

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