

# Osmo-air drying of pumpkin (*Cucurbitaceae maxima*) cubes and selection of suitable drying model

Sagar S. Shelke<sup>1</sup>, Pradip A. Borkar<sup>2</sup>, Rajesh P. Murumkar<sup>3</sup>, Mahendra R. Rajput<sup>4</sup>

<sup>1</sup>M. Tech. Scholar, <sup>2</sup>Associate Professor, <sup>3</sup>Assistant Professor, <sup>4</sup>Sr. Research Assistant  
Dr. Panjabrao Deshmukh Krishi Vidyapeeth (Agricultural University), Akola, India

## Abstract

In this study, the osmotic dehydration in 50, 60 and 70°Brix sugar solution at 30, 45 and 60°C syrup temperature) and drying air temperature (45, 55 and 65°C) on drying behaviour of pumpkin cubes were investigated. The pumpkin cubes were dried in a laboratory model tray dryer. Drying of pumpkin occurred in falling rate period. Four thin-layer drying models (Exponential, Page, Henderson and Pabis and Logarithmic) were fitted to the moisture ratio data. Among the drying models investigated, the Logarithmic model satisfactorily described the drying behavior of pumpkin cubes. The effective moisture diffusivity of osmo-convectively dried samples increased with increase in drying air temperature.

**Keywords:** Pumpkin; Drying; Mathematical models; Diffusivity.

## 1. Introduction

Pumpkin (*Cucurbita maxima*) belongs to *Cucurbitaceae* family. The knowledge of the nutritive value is to encourage the increase in the consumption and their use for nutritional and technological applications. Pumpkin is a good source of carotene, water soluble vitamins and amino acids. It is relatively in total solids, usually ranging between 7% to 10% (Arevalo-Pinedo and Murr, 2006; Alibas, 2007). This is rich in antioxidants and vitamins which allows the pumpkin to have an important health-protecting effect. In fact, the range of values of lipophilic substances as carotenoids present in pumpkin varieties can contribute significantly to the uptake of provitamin A and especially lutein, a carotenoid with special physiological functions (Murkovic *et al.*, 2005).

Pumpkins are also poor in total solids (Alibas, 2007) and in calories, which means that they are adequate for low calories regimes, and they are often recommended in diets. This vegetable is also known for the properties of its seeds, that are rich in fat, protein, thiamine, niacin and various minerals (Almeida, 2006).

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 & Das Gupta, 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 unfavorable changes in color, texture, flavor and nutritive value may occur.

To improve air-drying process, pre-treatment prior to drying is 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 color, aroma, nutritional constituents, and flavor 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 behavior, and for optimize the drying parameters. Recently, studies have been done on drying kinetics of fruits and vegetables (Sabarez & Price, 1999; Togrul & Pehlivan, 2002; Soysal, 2004; Doymaz, 2004; Cao et al., 2004; Jain & Pathare, 2004). However, work on the effect of pretreatments i.e. osmotic dehydration, on drying kinetics of pumpkin 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 pumpkin, (ii) to evaluate a suitable thin-layer drying model for describing the drying process, and (iii) to calculate the effective moisture diffusivity.

## 2. Materials and methods

### 2.1. Raw material

Pumpkin (*Cucurbitacae maxima*) for this investigation was procured from the College of Horticulture, Dr. Panjabrao Deshmukh Krishi Vidyapeeth (Agricultural University), Akola (Maharashtra). Fresh whole pumpkin of 'Vishal' variety were washed, peeled, sliced. The slices were cut into 10 × 10 × 10 mm cubes using stainless still cutter. The initial moisture content was determined by AOAC methodology no. 934.06 (AOAC, 1990), which was 89-92 % wb.

### 2.2 Osmotic dehydration

Pumpkin cubes were partially dehydrated using osmotic dehydration technique. The cubes were placed in different containers holding 50, 60 and 70 °Brix of sugar solution at temperatures (50, 60 and 70°C) for 4 h; and stirring of the solution was done at regular intervals of 15 minutes. Syrup to fruit ratio was kept constant as 4:1. After a period of 4 h, cubes were removed quickly and blotted gently using a tissue paper to remove the surface moisture.

### 2.3. Hot-air-drying

The pumpkin samples were osmotically dehydrated in (50, 60 and 70 °Brix sugar solution). A Response Surface Methodology (RSM) was used to optimize the concentration (53.98°Brix), temperature (57.50°C) and duration of osmosis (239.99 min). The samples were then dried in a laboratory tray dryer. The schematic diagram of the dryer is shown in Figure 1. The dryer consisted of a drying chamber, blower, fan and a temperature controller. Experiments were conducted at 45, 55 and 65°C air temperature and at a constant airflow velocity of 1.5 m/s. After the dryer reached the set conditions, pumpkin cubes (150g) were uniformly spread on each tray and were kept in dryer. Moisture loss was recorded at every 30 minutes interval by a digital balance of 0.01g accuracy. The drying was continued until there was no large

variation in the moisture loss. Experiments were replicated thrice. A total 3 treatments combination as described in **Table 1** was conducted.

#### 2.4. Mathematical modelling

Mathematical modeling 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 behavior than that of moisture content curve, the moisture ratio values were used to predict the drying model for osmo-convectively dried samples of pumpkin. To select a suitable model for describing the drying process of pumpkin cubes, drying curves were fitted with four thin-layer drying equations, namely Exponential (Eq. (1)), Page (Eq. (2)), Henderson–Pabis (Eq. (3)), Logarithmic (Eq. (4)). (Akpinar et al., 2005; Doymaz, 2004; Togrul & Pehlivan, 2002).

$$\text{Exponential } MR = \exp(-kt) \quad \dots (1)$$

$$\text{Page } MR = \exp(-kt^n) \quad \dots (2)$$

$$\text{Henderson-Pabis } MR = a \exp(-kt) \quad \dots (3)$$

$$\text{Logarithmic } MR = a + b \ln(t) \quad \dots (4)$$

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 reduced mean square of the deviation  $\chi^2$  and root mean square error  $E_{RMS}$ . For quality fit,  $R^2$  value should be higher close to one and  $\chi^2$  and  $E_{RMS}$  values should be lower (Pangavhane et al., 1999; Sarsavadia et al., 1999; Togrul & Pehlivan, 2002; Erenturk et al., 2004; Demir et al., 2004). The above parameters can be calculated as follows:

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

$$E_{RMS} = \left[ \frac{1}{N} \sum_{i=1}^N (M_{R,pre,i} - M_{R,exp,i})^2 \right]^{1/2} \quad \dots (7)$$

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.

### 3. Results and discussion

#### 3.1 Drying behaviour of osmo- convectively dried pumpkin cubes

The effect of osmotic and drying temperature on the time taken to reach the final moisture content is presented in **Table 1**. Drying air temperature had an important effect on drying. At the higher temperature, due to the quick removal of moisture, the drying time was less. Similar observations have been reported for drying of garlic slices (Madamba et al., 1996), onion slices (Sarsavadia et al., 1999) and egg plants (Akpinar & Bicer, 2005). The final moisture content of osmotically dried samples dried under different conditions was ranged from 2 per cent to 4 per cent (d.b.) and 14 per cent to 25 per cent (d.b.) respectively. It is evident that pre-treatment had effect on moisture movement from the samples. It also observed from **Table 1**, as the sugar concentration ( $^{\circ}$ Brix) increase, drying time increased, at same drying temperature, this could be due to solid gain into the product, which slowed down the

dehydration rate of pumpkin cubes also pre-treatment of fruits in sugar solutions usually reduces the convective drying rates (Simal et al., 1997, Karathanos & Kostaropoulos, 1995, Rahman and Lamb, 1991).

Effect of osmotic on drying curves of pumpkin cubes dried at 45, 55 and 65°C are presented in Figure 2. The drying curves show that moisture ratio decreases continuously with drying time. Pumpkin cubes did not exhibit a constant rate period of drying. The entire drying took place in the falling rate period. Similar results have been reported for the drying studies on onion slices (Rapusas & Driscoll, 1995) and apricots (Doymaz, 2004). 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 & Maguer, 1980), lettuce and cauliflower leaves (Lopez et al., 2000) and figs (Piga et al., 2004).

### 3.2 Mathematical modeling of drying curves

The moisture ratio data of osmotically dried pumpkin cubes dried at various temperatures were fitted into the different thin-layer drying models mentioned above. The values of ( $R^2$ ),  $\chi^2$  and  $E_{RMS}$ , are summarized in Table 2.

It was observed that in all cases, the values of  $R^2$  was greater than 0.90, indicating a good fit (Madamba et al., 1996; Erenturk et al., 2004). But the logarithmic model gave comparatively higher  $R^2$  values in all the drying treatment (0.996-0.999) and also the  $\chi^2$  (0.000 – 0.01) and  $E_{RMS}$  (-0.001 - 0.003) values were lower. Hence, the Logarithmic model may be assumed to represent the thin-layer drying behaviour of pumpkin cubes. Demir et al. (2004) and Goyal et al. (2006) reported a similar result for air-drying of bay leaves and raw mango slices, respectively.

Figures 3, 4 and 5 shows a comparison between both observed and predicted moisture values obtained using the Logarithmic model, which gave the best fit for the entire Pumpkin drying process. This means that the model has very high performance for describing the characteristics of drying curves.

### 3.3 Calculation of 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 (Pumpkin cubes was considered to be infinite plate shape)

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

For long drying periods, Eqn (8) can be further simplified to only the first term of the series.

$$\ln\left(\frac{M - M_e}{M_0 - M_e}\right) = \ln \frac{8}{\pi^2} - \left(\frac{\pi^2 D_{eff} t}{4H^2}\right) \quad \dots (9)$$

Where,  $M_R$  is the dimensionless moisture ratio,  $M$  the moisture content at any time (g H<sub>2</sub>O/g dry matter),  $M_0$  the initial moisture content (g H<sub>2</sub>O/g dry matter),  $M_e$  the equilibrium moisture content (g H<sub>2</sub>O/g dry matter),  $D_{eff}$  the effective diffusivity (m<sup>2</sup>/s),  $H$  the half thickness of slab in sample (m),  $n$  the positive integer,  $t$  the Time (s).

A general form of Eq. (9) could be written in semi-logarithmic form, as follows.

$$\ln(M_R) = A - Bt \quad \dots (10)$$

The effective diffusivity is typically calculated by plotting experimental drying data in terms of  $\ln(M_R)$  versus drying time. From Eqn (10), a plot of  $\ln(M_R)$  versus the drying time gives a straight line with a slope of:

$$\text{Slope} = \frac{\pi^2 D_{\text{eff}}}{4H^2} \quad \dots (11)$$

Drying at higher temperature gave highest  $D_{\text{eff}}$  values. The moisture diffusivity value of food material was affected by moisture content as well as temperature. At lower level of moisture content the diffusivity is less than that of high moisture content. Also it was observed that moisture diffusivity increased with drying air temperature in osmotically dried samples which is in accordance of the results reported by **Rahman and Lamb, (1991)** and **Pokharkar and Prasad (1998)**. The moisture diffusivity varied in the range of  $9.73 \times 10^{-08} \text{m}^2/\text{s}$ ,  $11.68 \times 10^{-08} \text{m}^2/\text{s}$  and  $14.92 \times 10^{-08} \text{m}^2/\text{s}$  for osmo-convectively dried samples depending on the drying air temperature (**Table 1**). These values are within the general range of  $10^{-08}$  to  $10^{-12} \text{m}^2/\text{s}$  for drying of food materials (**McMinn and Magee, 1999**).

#### 4. Conclusions

The effect of temperature and osmo-convective drying behavior of Pumpkin cubes in tray dryer was investigated in this study. Increase in drying air temperature from 45 to 65°C decreased the drying time from 240 to 360 min for osmo-convectively dried samples. The entire drying process occurred in falling rate period and constant rate period was not observed. Four thin-layer drying equations were investigated for their suitability to describe the drying behavior of pumpkin cubes. The Logarithmic model shows the best fit with high values for the coefficient of determination (0.996-0.999) and low  $\chi^2$  and  $E_{RMS}$  values. The effective moisture diffusivity varied from in the range of  $9.73 \times 10^{-08} \text{m}^2/\text{s}$  to  $14.92 \times 10^{-08} \text{m}^2/\text{s}$  for osmo-convectively dried samples at different drying air temperature.

#### Acknowledgements

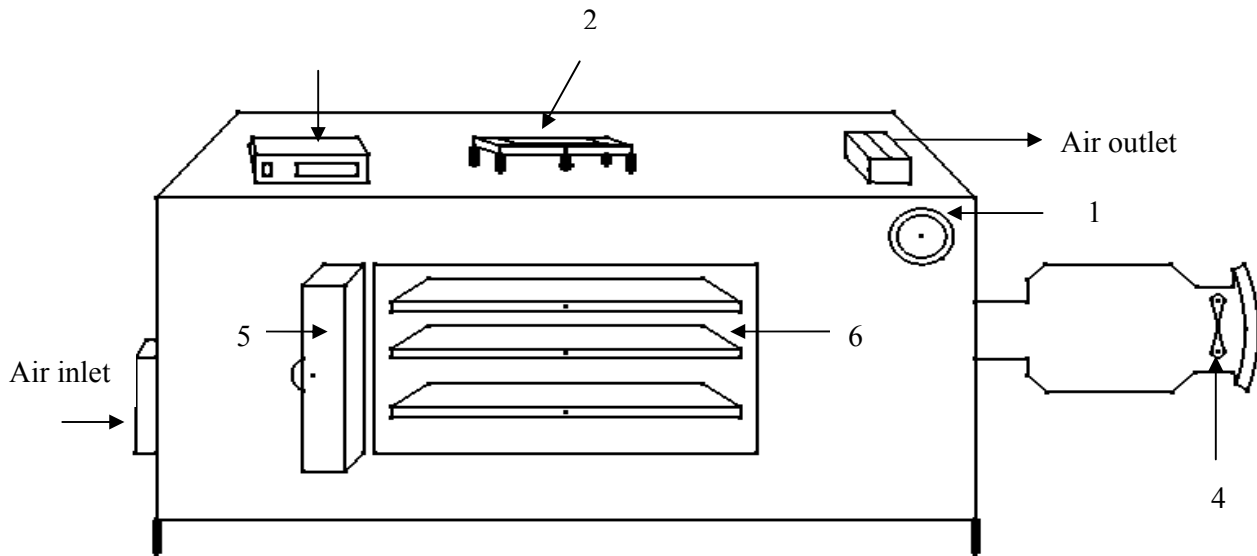
The authors are highly thankful to All India Coordinated Research Project on Post Harvest Technology, Dr. Panjabrao Deshmukh Agricultural University, Akola, Maharashtra, India for providing facilities to carry out this research work.

#### [References]

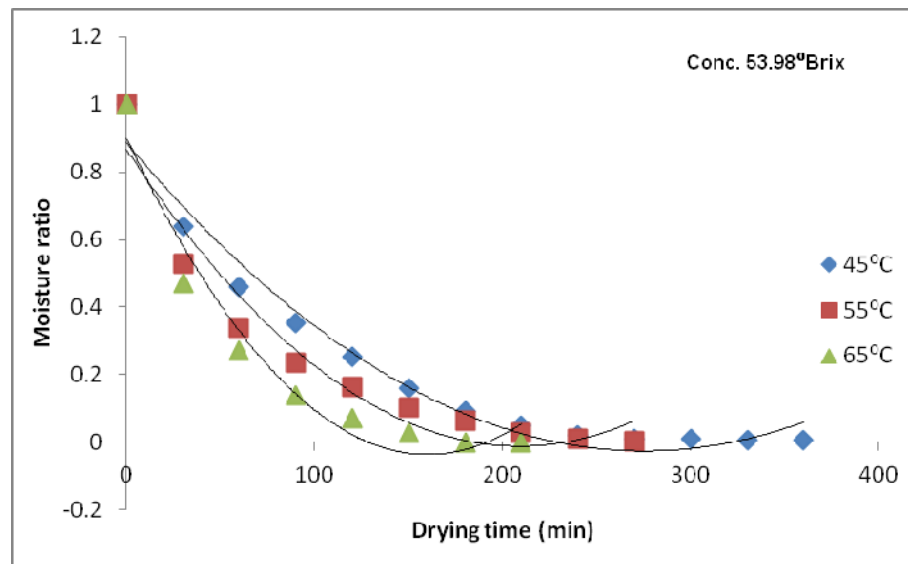
- [1] Akpınar, E.K., Bicer, Y., 2005. Modelling of the drying eggplants in thin-layers. *International Journal of Food Science & Technology* 40, 273-281.
- [2] Alibas I. 2007. Microwave air and combined microwave-air-drying parameters of pumpkin slices. *LWT*40(8):1445-1451
- [3] Almeida D., 2006. *Manual de culturas horticolas*. Editorial Presenca, Portugal, Lisboa, p. 111.
- [4] AOAC, 1990. *Official method of analysis of the Association of Official Analytical Chemist*. No. 934.06. Arlington, USA.
- [5] Arevalo-Pinedo and Murr F. E. X., 2006 Kinetics of vacuum drying of pumpkin (*cucurbita maxima*): modeling with shrinkage. *Journal of Food Engineering* 76, 562-567
- [6] Beaudry, C., 2001. Evaluation of drying methods on osmotically dehydrated canberries. Unpublished M.Sc. thesis. Montreal, QC: Department of Agricultural and Biosystem Engineering, McGill University.

- [7] Beppu, H., Nagamura, Y., Fujita, K., 1993. Hyglycaemic & antidiabetic effects in mice of *Aloe arborescens* Miller var. *natalensis* berger. *Phytotherapy Research* 7, 37- 42.
- [8] Cao, W., Nishiyama, Y., Koide, S., 2004. Simulation of intermittent drying of maitake mushroom by a simplified model. *Biosystems Engineering* 87(3), 325 – 331.
- [9] Crank, J., 1975. *The mathematics of the diffusion*. Oxford university press, London. 39-58.
- [10] Demir, V., Gunhan, T., Yagcioglu, A.K., Degirmencioglu, A., 2004. Mathematical modelling & the determination of some quality parameters of air-dried bay leaves. *Biosystems Engineering* 88(3), 325 - 335.
- [11] Doymaz, I., 2004. Effect of pre-treatments using potassium metabisulphide & alkaline ethyl oleate on the drying kinetics of apricots. *Biosystems Engineering* 89(3), 281 – 287
- [12] Erenturk, S., Gulaboglu, M.S., Gultekin, S., 2004. The thin-layer drying characteristics of rosehip. *Biosystems Engineering* 89(2), 159 - 166.
- [13] Goyal, R.K., Kingsly, A.R.P., Manikantan, M.R., Ilyas, S.M. 2006. Thin-layer drying kinetics of raw mango slices. *Biosystems Engineering* 95(1), 43 - 49.
- [14] Jain, D., Pathare, P.B., 2004. Selection and evaluation of thin layer drying models for infrared radiative and convective drying of onion slices. *Biosystems Engineering* 89(3), 289 – 296
- [15] Jarayaman, K.S., Das Gupta, D.K., 1995. Drying of fruits and vegetables. In A. S. Mujumdar (Ed.), *Handbook of industrial drying* (pp. 643–690). New York: Marcel Dekker Inc.
- [16] Karathanos, V.T., Kostaropoulos, A.E., Saravacos, G.D., 1995. Air drying kinetics of osmotically dehydrated fruits. *Drying Technology* 13(5-7), 1503 - 1521.
- [17] Lenart, A., 1996. Osmo-convective Drying of Fruits and Vegetables: technology and application. *Drying Technology* 14(2), 391.
- [18] Lopez, A., Iguaz, A., Esnoz, A., Virsed, P., 2000. Thin-layer drying behaviour of vegetable wastes from wholesale market. *Drying Technology* 18, 995-1006.
- [19] Madamba, P.S., Driscoll, R.H. & Buckle, K.A., 1996. The thin-layer drying characteristic of garlic slices. *Journal of Food Engineering* 29, 75–97.
- [20] Mazza, G., Maguer, M.L., 1980. Dehydration of onion: some theoretical and practical considerations. *Journal of Food Technology* 15, 181-194.
- [21] McMin, W.A.M., Magee, T.R.A., 1999. Principles, methods and applications of the convective drying of foodstuffs. *Transactions of Institution of Chemical Engineers* 77(c): 175-193.
- [22] Murkovic M, Mulleder U and Neunteufl H (2005) Carotenoid content in different varieties of pumpkins. *Journal of Food Composition and Analysis*, 15, 633-638.
- [23] Okos, M.R., Narasimhan, G., Singh, R.K., Witnauer, A.C., 1992. Food dehydration. In D. R. Heldman, & D. B. Lund (Eds.), *Handbook of food engineering*. New York: Marcel Dekker.
- [24] Pangavhane, D.R., Sawhney, R.L., Sarsavadia, P.N., 1999. Effect of various dipping pre-treatment on drying kinetics of Thompson seedless grapes. *Journal of Food Engineering* 39, 211-216.
- [25] Piga, A., Pinna, I., Ozer, K.B., Agabbio, M., Aksoy, U., 2004. Hot air dehydration of figs (*Ficus carica* L.): drying kinetics and quality loss. *International Journal of Food Science and Technology* 39, 793-799.

- [26] Pokharkar, S.M., Prasad, S., 1998. Mass transfer during osmotic dehydration of banana slices. *Journal of Food Science and Technology* 35(4), 336-338.
- [27] Rahman, M. S & Lamb, J. (1991). Air drying behaviour of fresh and osmotically dehydrated pineapple. *Journal of Food Process Engineering*, 14, 163-171.
- [28] Rapusas, R.S., Driscoll, R.H., 1995. The thin-layer drying characteristics of white onion slices. *Drying Technology* 13(8&9), 1905-1931.
- [29] Sabarez, H.T., Price, W.E. 1999. A diffusion model for prune dehydration. *Journal of Food Engineering* 42, 167-172
- [30] Sarsavadia, P.N., Sawhney, R.L., Pangavhane, D.R., Singh, S.P., 1999. Drying behaviour of brined onion slices. *Journal of Food Engineering* 40, 219-226.
- [31] Simal, S., Deya, E., Frau, M., Rossello, C., 1997. Simple Modelling of Air Drying Curves of Fresh and Osmotically Predehydrated Apple Cubes. *Journal of Food Engineering* 33, 139.
- [32] Soysal, Y., 2004. Microwave drying characteristics of parsley. *Biosystems Engineering*, 89(2), 167-173
- [33] Togrul, I.T., Pehlivan, D., 2002. Mathematical modelling of solar drying of apricots in thin-layers. *Journal of Food Engineering* 55, 209-216

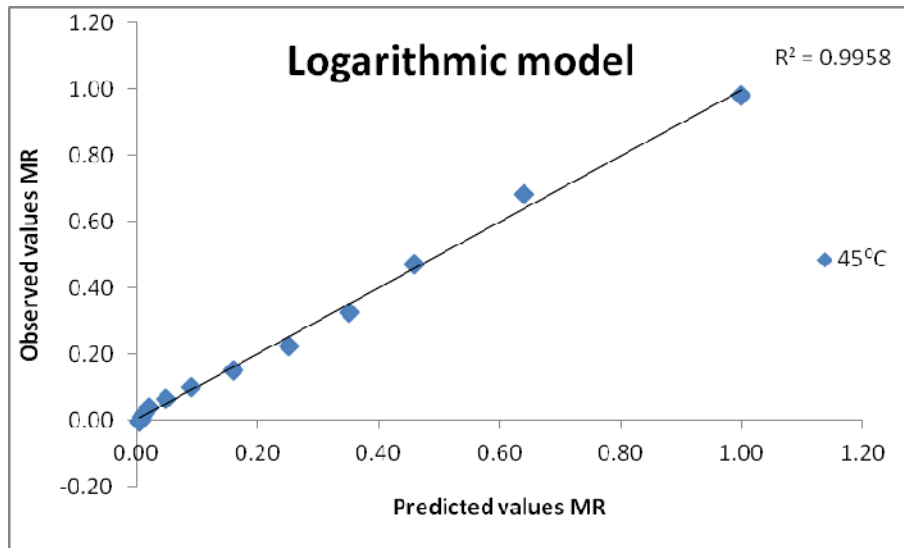


**Fig. 1.** Schematic diagram of tray dryer: (1) Thermocouples (2) Digital balance (3) (4) Blower (5) Door (6) Trays

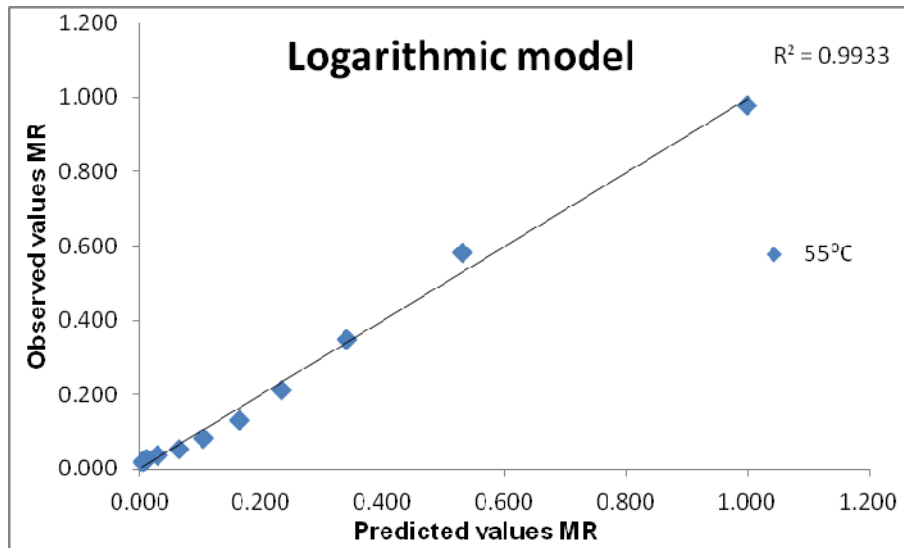


**Fig 2** Effect on osmo-convective drying for concentration of 53.98°Brix at temperature of 45, 55 and 65°C.

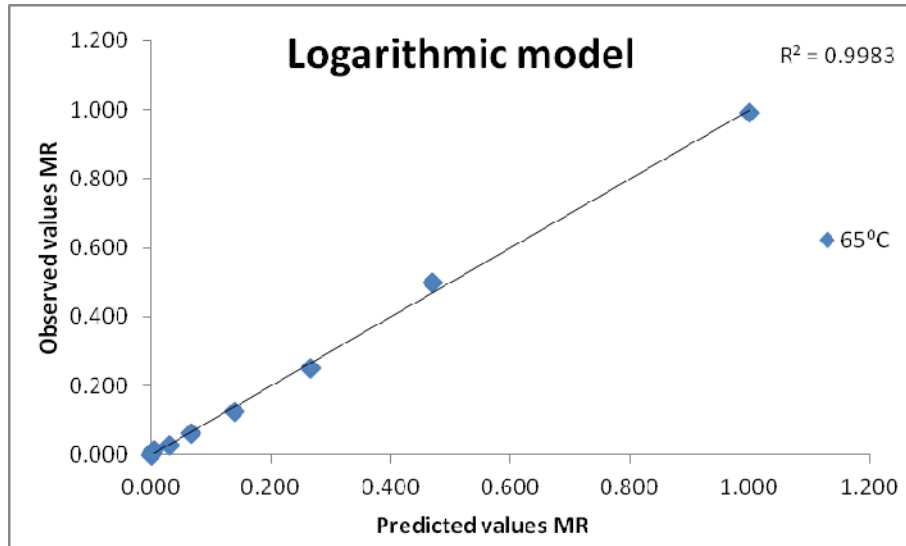




**Fig 3 Observed and predicted values of moisture ratio by logarithmic model for 45°C temperature.**



**Fig 4 Observed and predicted values of moisture ratio by logarithmic model for 55°C temperature.**



**Fig 5** Observed and predicted values of moisture ratio by logarithmic model for 65°C temperature.

**Table 1** Drying time and Effective moisture diffusivity for pumpkin cubes

Treatment	Temperature of osmotic solution (°C)	Syrup concentration (°Brix)	Temperature of drying (°C)	Drying time (min)	Diffusivity (m <sup>2</sup> /s)	R <sup>2</sup> values
1	57.50	53.98	45	240	9.73×10 <sup>-7</sup>	0.982
2	57.50	53.98	55	300	11.68×10 <sup>-7</sup>	0.975
3	57.50	53.98	65	360	14.92×10 <sup>-7</sup>	0.998

Name of models and it's equations	Temp °C	Drying constant			Statistical parameters		
		k	n	a	R <sup>2</sup>	χ <sup>2</sup>	ERMS
Exponential $MR = \exp(-kt)$	45	0.009			0.963	0.006	0.003
	55	0.010			0.950	0.011	0.016
	65	0.013			0.924	0.016	0.057
Henderson and Pabis $MR = a \exp(-kt)$	45	1.439	0.012		0.997	0.005	0.000
	55	1.610	0.016		0.996	0.009	0.001
	65	1.983	0.023		0.999	0.000	0.000
Page $MR = \exp(-kt^n)$	45	- 0.000	1.252		0.990	0.001	0.003
	55	- 0.000	1.564		0.979	0.053	0.001
	65	- 0.000	2.041		0.982	0.004	0.057
Logarithmic $MR = a \cdot \exp(kt) + c$	45	1.424	0.011	- 0.020	0.997	0.000	0.000
	55	1.634	0.017	0.123	0.996	0.001	-0.001
	65	1.972	0.022	- 0.003	0.999	0.000	0.003

**Table 2 Values of model constants and statistical parameters**

Where,

- a, b drying coefficients
- $D_{\text{eff}}$  effective diffusivity in  $\text{m}^2/\text{s}$
- $E_{RMS}$  root mean square error
- $H$  half thickness of slab in sample in, m
- k drying constant
- $M$  moisture content at any time, g  $\text{H}_2\text{O}/\text{g}$  dry matter
- $M_0$  initial moisture content, g  $\text{H}_2\text{O}/\text{g}$  dry matter
- $M_e$  equilibrium moisture content, g  $\text{H}_2\text{O}/\text{g}$  dry matter
- $M_R$  moisture ratio, dimensionless
- N number of observations
- n drying constant, positive integer
- R<sup>2</sup> coefficient of determination
- t time (s)
- χ<sup>2</sup> reduced mean square of the deviation
- z number of drying constants.

*Subscripts*

- pre predicted
- exp experimental