

## Effects of Temperature and Slice Thickness on Drying Kinetics of Pumpkin Slices

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### Abstract

Dried pumpkin slice is an alternative crisp food product. In this study, the effects of temperature and slice thickness on the drying characteristics of pumpkin were studied in a lab-scale tray dryer, using hot air temperatures of 55, 60 and 65 °C and 2, 3 and 4 mm slice thickness at a constant air velocity of 1.5 m/s. The initial moisture content of the pumpkin samples was  $90 \pm 0.5$  % (wb). The drying process was carried out until the final moisture content of product was  $10 \pm 0.5$  % (wb). The results showed that the drying time decreased with increasing drying temperature, but it increased with increasing slice thickness of the pumpkin. In all tests, the experimental drying curves obtained show results for only the falling rate period.

Fick's diffusion equation has been used to model the drying characteristics and fits all experimental data. The effective moisture diffusivity during drying varied from  $1.359 \times 10^{-10}$  to  $5.301 \times 10^{-10}$  m<sup>2</sup>/s. The effective moisture diffusivity results were in agreement with previously reported diffusivity values.

**Keywords:** Pumpkin, convective drying, drying kinetics, effective moisture diffusivity, activation energy

### Introduction

Pumpkin is a traditionally produced fruit that is grown around the world for a variety of purposes ranging from agricultural to commercial and ornamental. The pumpkin belongs to the family of Cucurbitaceae and varieties include *Cucurbita moschata*, *C. pepo*, *C. maxima*, *C. mixta*, etc. The traditional pumpkin in Thailand is the fruit of the species *Cucurbita moschata Decne.* It is considered to be a good source of carotenoids, and a very rich source of carotene [1]. The main nutrient is beta carotene, which generates vitamin A in the body. The perishable nature of this fruit limits its utilization. It has been processed in different ways, such as frying or drying, for human consumption.

Drying is one of the most widely used methods of fruit preservation, in which water is removed from the fruit to the level at which microbial spoilage and deterioration reactions are greatly minimized [2]. This provides longer shelf-life and lighter weight for storage [3]. Natural sun

drying is widely practiced in most tropical countries. However, the final product can be affected by contamination from insects, dust, or spoilage resulting from rain during drying [4] so that the drying of agricultural products needs to be undertaken in a closed dryer such as a solar dryer, or an industrial dryer using a convective method. Use of a cabinet dryer is an alternative drying method that both decreases the drying time and improves the quality of the final product [2,5]. It is a low-cost method that is used for various foods such as banana [6], pumpkin [7], steamed glutinous rice [8], etc. In this process hot air heats the samples to remove the moisture. The removal of water from food products depends on not only drying temperature [6-7,9-10] but also slice thickness [6,11]. It is known that the drying conditions and also the sample geometry affect the quality of the dried product.

In recent years, many researchers have investigated the effect of various parameters of the

drying kinetics of dehydrated pumpkin using different methods. For example, Doymaz [7] observed the effect of drying temperatures (50, 55 and 60 °C) on the drying characteristics of pumpkin cut into cylindrical slices of  $0.7 \pm 0.03$  cm. Nawirska *et al.* [12] investigated 12 pumpkin cultivars, cutting slices into a cylindrical shape (3.5 mm thick and 18 mm in diameter) and drying them at 60 °C, and also observed the kinetics of their dehydration by convective and vacuum-microwave methods. Arevalo-Pinedo and Murr [9] compared the influence of freezing and blanching as pre-treatments on the drying kinetics of pumpkin at temperatures of 50, 60 and 70 °C and in a vacuum chamber of 5 and 15 kPa, cutting the pumpkin into slabs with a thickness of 5 mm a length 40 mm and a width of 20 mm.

In the drying industry, there is also a commercial interest in the use of a sieve-tray dryer to achieve maximum moisture removal in the case of the production of a thinly sliced product. There is, however, little reported work demonstrating the drying kinetics of thin pumpkin slices cut into rectangular slices at various thicknesses and dried at various temperatures.

The present study aim to determine the influence of drying temperature and slice thickness on the drying kinetics of pumpkin slices dried in a sieve-tray dryer. Pumpkin slices at different thicknesses (2, 3 and 4 mm) were dried at 55, 60 and 65 °C with a drying air velocity of 1.5 m/s.

## Materials and methods

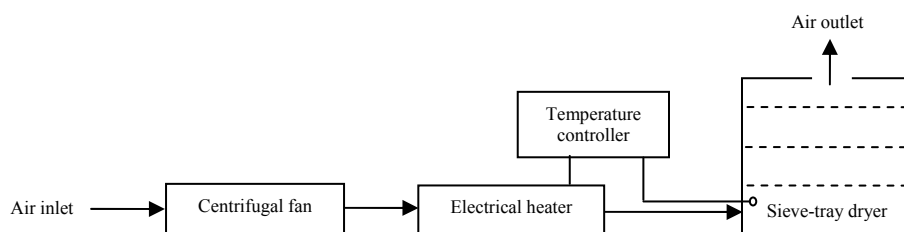
### Preparation of material

Fresh pumpkins (*Cucurbita moschata* Decne) purchased from a local market in Nakhon Si Thammarat province, Thailand were peeled and cut into slab pieces 2, 3 and 4 mm thick with a length of 25.4 mm and a width of 25.4 mm.

Pumpkin slices of each thickness were blanched for 1 min in hot water (90 °C), cooled by placing on a sieve at room temperature, soaked in  $\text{CaCl}_2$  solution (0.7 w/v %) for 30 min. Excess surface water was then absorbed using tissue paper.

### Drying procedures

Pumpkin slices were dried in the sieve-tray dryer (**Figure 1**) installed in the Food Technology laboratory of Walailak University, Thailand. The tray dryer was equipped with an electrical heater with a PID temperature controller. The air velocity in the dryer, measured with an anemometer with a precision of  $\pm 0.1$  m/s, was 1.5 m/s, with an air current being produced by a centrifugal fan. The dryer was run for 30 min to achieve the desired temperature at steady-state conditions before the commencement of the drying experiments. Experiments were performed at 55, 60 and 65 °C for drying pumpkins at different thicknesses (2, 3 and 4 mm). The relative humidity (RH) at each temperature inside the dryer was calculated by measuring the dry and wet bulk temperatures and was 18.5, 14.5 and 10.5 % in air temperatures of 50, 55 and 65 °C, respectively. The initial moisture content of the pumpkin samples was  $90 \pm 0.5$  % (wb) determined by a hot air oven at 105 °C for 12 h. The samples, weighing about 500 g, were placed on the top sieve tray and formed a single layer uniformly within the tray dryer so that hot air could pass freely around each slice. The weight of the samples in the tray was recorded at 30 min intervals during drying to determine the drying curves, using a digital balance of 0.0001 g precision. The drying process was carried out until the final moisture content of product was about  $10 \pm 0.5$  % (wb). All experiments were replicated in duplicate and the average values of the data were reported.



**Figure 1** Schematic diagram of the tray dryer.

### Mathematical modeling

The moisture content based on dry basis is the weight of water present in the sample per unit weight of dry solid in the sample, calculated by the following equations:

For initial moisture content:

$$M_0 = \frac{W_0 - W_d}{W_d} \quad (1)$$

where  $W_0$  is the initial weight of the sample and  $W_d$  is the weight of the dry solid.

For moisture content at any time:

$$M_t = \left[ \frac{(M_0 + 1)W_t}{W_0} - 1 \right] \quad (2)$$

where  $W_t$  is the weight of the sample at any time.

The moisture ratio ( $MR$ ) at any time and the drying rate of the sample during drying period ( $dt$ ) were calculated by the following equations:

$$MR = \frac{M_t - M_e}{M_0 - M_e} \quad (3)$$

$$\text{Drying rate} = \frac{(M_{t-dt} - M_t)W_d}{dt} \quad (4)$$

where  $M_{t-dt}$  and  $M_t$  are the moisture contents at  $t-dt$  and  $t$ , respectively, and  $dt$  is the drying time.  $M_e$  is the equilibrium moisture content of the sample when the drying rate is zero [6]. Generally, most food drying processes take place in the falling rate period. For the pumpkin slices, the second Fick's law equation was used for long drying times to calculate the diffusion coefficient for water in the falling rate period, as in the following equation [7,13].

$$MR = \frac{8}{\pi^2} \exp\left[-\frac{\pi^2 D_{eff} t}{4L^2}\right] \quad (5)$$

where  $D_{eff}$  is the effective diffusion coefficient of water ( $m^2/s$ ), and  $L$  is the thickness of the raw sample if drying occurred on one face (m). In this study slices were placed on a sieved tray so that drying occurred on two faces, so  $L$  is half the slice thickness. The  $D_{eff}$  values were calculated from the slopes of curves plotted as  $\ln MR$  values versus drying time ( $t$ ). The relationship between  $D_{eff}$

values and drying temperatures can be calculated using the Arrhenius equation:

$$D_{eff} = D_0 \exp\left[-\frac{E_a}{RT}\right] \quad (6)$$

where  $D_0$  is the constant in the Arrhenius equation ( $m^2/s$ ),  $E_a$  is the activation energy (kJ/mol),  $R$  is the universal gas constant (8.314 kJ/mol K), and  $T$  is the absolute temperature of drying air (K). The activation energy was estimated from the slope of the plot on  $\ln(D_{eff})$  versus  $1/T$ . The parameters of Fick's model (Eq. 5), and the Arrhenius equation (Eq. 6) were estimated by the linear regression procedure of Excel 2007 and SigmaPlot version 11.2.

### Results and discussion

#### Influence of drying temperature and slice thickness on drying time

For all the experiments, the samples having an initial moisture content of  $90 \pm 0.5$  % (wb) were dried to reach a final moisture content of  $10 \pm 0.5$  % (wb). The influence of the drying temperature on pumpkin at each of three sample thicknesses, namely 2, 3 and 4 mm, is shown in **Figures 2 - 4**, representing the moisture ratio versus drying time. It is clearly evident that the moisture ratio decreased continuously with drying time. At constant sample thickness, the increase in temperature reduced the drying time needed to reach a moisture content of about 10 % wet basis. This was due to the increased energy of water molecules when the temperature was increased, as the evaporation of water molecules from the sample occurs more quickly.

The change in moisture content of sample versus drying time, for various sample thicknesses at a drying temperature of 55 °C, is shown in **Figure 5**. It was also found that greater sample thickness required a longer drying time due to the increased distance travelled by moisture to the surface. Similar trends were also observed at drying temperatures of 60 and 65 °C.

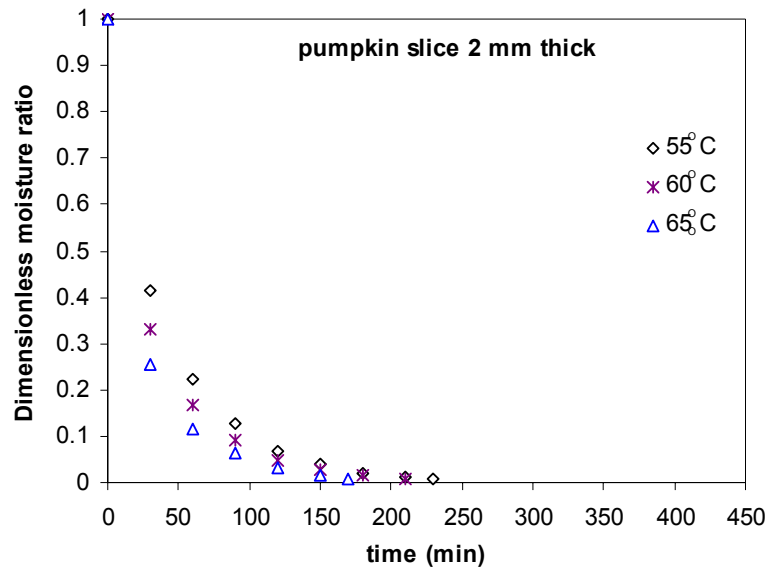


Figure 2 Effect of temperature on the moisture ratio of the pumpkin slices at any drying time.

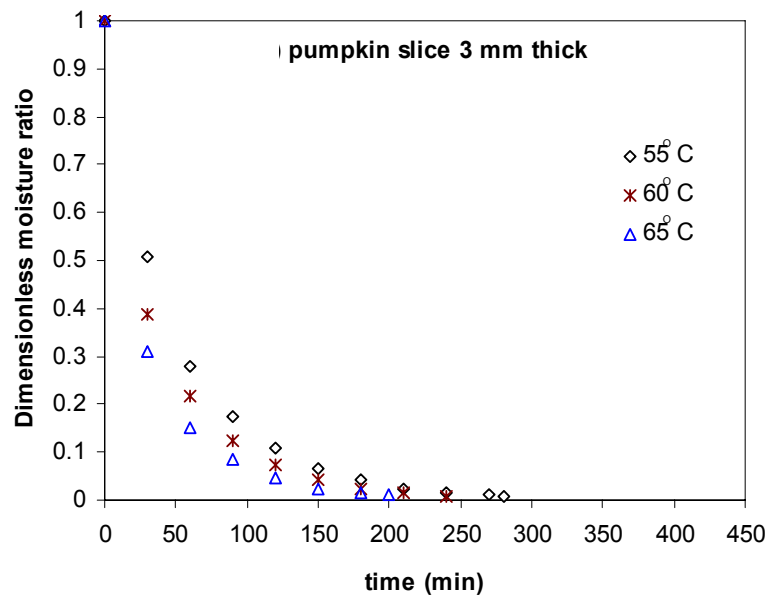
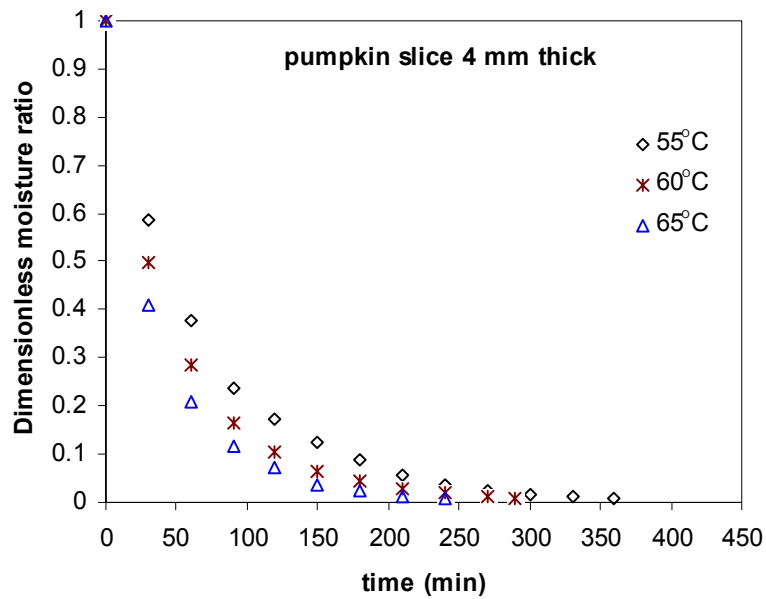
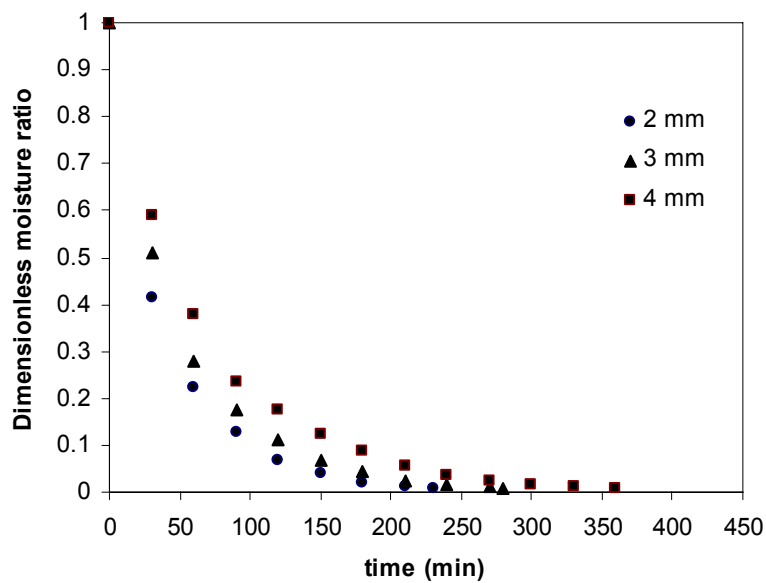


Figure 3 Effect of temperature on the moisture ratio of the pumpkin slices at any drying time.



**Figure 4** Effect of temperature on the moisture ratio of the pumpkin slices at any drying time.



**Figure 5** Effect of slice thickness on the moisture ratio of the pumpkin slices during drying at 55 °C.

Drying times for reducing moisture content from an initial moisture content of  $90 \pm 0.5$  % (wb) to  $10 \pm 0.5$  % (wb) for all experiments are given in **Table 1**. The time used to reduce the moisture ratio to the given level was as expected; that is, the reduction of moisture ratio of the

sample depended on both the drying temperature and the thickness of the pumpkin slices, being highest at 55 °C for drying pumpkin slices 4 mm thick, and lowest at 65 °C for drying pumpkin slices 2 mm thick.

### Modelling the drying kinetics of pumpkin

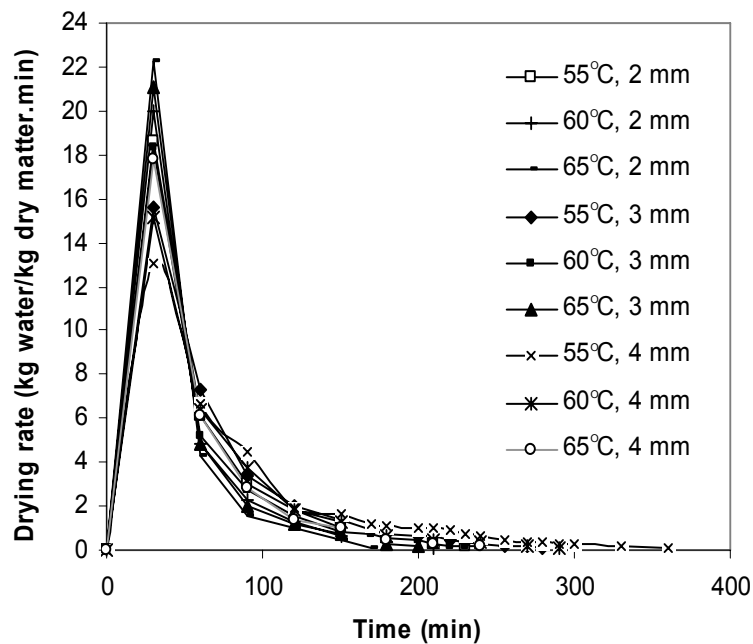
The drying rate versus time curves for all tests are shown in **Figure 6**. From these curves it can be seen that the entire drying process for pumpkin took place only in the falling rate period for all of the tests. Pumpkin slices dried out very fast, especially the thin slice at high temperature. The non-existence of a constant rate period may be explained by the fact that the surface of the pumpkin slices was not covered by free water regions at any time, so that the evaporation of water did not take place at a constant

rate. This result is in agreement with previous literature studies on the drying of foods [2].

In order to explain the drying characteristics of pumpkin under different drying conditions, it is necessary to model the drying process. The drying of pumpkin predominantly follows a falling rate period. The mass transfer during the drying period is entirely caused by liquid diffusion or capillary flow. Fick's diffusion equation is widely used to model the drying characteristic for the drying period.

**Table 1** Drying time (min) for drying to reach the final moisture content of  $10 \pm 0.5$  % (wb) at different temperatures and slice thicknesses.

$T(^{\circ}C)$	Sample thickness (mm)		
	2	3	4
55	230	280	360
60	210	240	290
65	170	200	240



**Figure 6** The drying rate versus time curves for all tests.

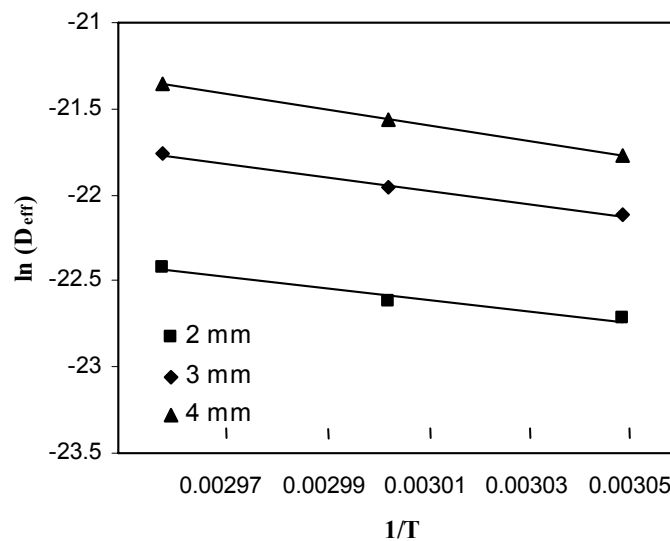
The effective diffusion coefficient values ( $D_{eff}$ ) obtained from different drying conditions are presented in **Table 2**. It can be seen that the values of effective diffusion coefficient increased with increasing temperature. This is similar to the results reported by Doymaz [7] for air-drying of pumpkin slices (thickness of 0.7 cm, at 50 - 60 °C), and Nguyen and Price [6] for air-drying of banana slices (thickness of 1 and 2 cm, at 50 - 70

°C). The values reported were within the general range of  $10^{-11}$  to  $10^{-9}$  m<sup>2</sup>/s for food materials.

The activation energy values estimated from the slopes of straight lines from plotting  $\ln(D_{eff})$  versus  $1/T$  are presented in **Figure 7**. The values of  $E_a$  for each sample thickness are shown in **Table 3**. It is obvious that the activation energy values increased with increasing slice thickness, showing the sensitivity of  $D_{eff}$  values to the slice thickness, i.e. the higher the activation energy, the higher the effect of sample thickness on  $D_{eff}$  values.

**Table 2** Effective diffusion coefficient of water in pumpkin slices for all tests.

T (°C)	Sample thickness (mm)	Effective diffusion coefficient of water ( $D_{eff} \times 10^{-10}$ m <sup>2</sup> /s)	Standard deviation (R <sup>2</sup> )
55	2	1.3591	0.9976
	3	2.4798	0.9984
	4	3.5160	0.9983
60	2	1.5078	0.9861
	3	2.9210	0.9934
	4	4.3274	0.9960
65	2	1.8392	0.9817
	3	3.5295	0.9848
	4	5.3011	0.9919



**Figure 7** Effect of drying temperature on the effective diffusion coefficient of water for each thickness of pumpkin slices.

**Table 3** The activation energy values for all tests.

Sample thickness (mm)	Activation energy values (kJ/mol)	Standard deviation (R <sup>2</sup> )
2	27.8361	0.9652
3	32.5210	0.9975
4	37.8437	1.0000

### Conclusions

The influence of temperature and slice thickness on the drying kinetics of pumpkin was investigated in this study. A shorter drying time for pumpkin slices and an increased drying rate resulted from the beneficial effects of increasing drying temperature and decreasing slice thickness. The drying process took place in the falling rate period. The effective moisture diffusivity during drying varied from  $1.359 \times 10^{-10}$  to  $5.301 \times 10^{-10}$  m<sup>2</sup>/s, in the range from  $10^{-11}$  to  $10^{-9}$  m<sup>2</sup>/s reported for other food stuffs. The results of effective moisture diffusivity were seen to be in agreement with the reported diffusivity values.

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