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Studies on drying kinetics of convective hot air drying of pumpkin slices

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Abstract
In a lab-scale tray dryer, hot air temperatures of 60, 70, and 80°C and slice thickness of 3, 6, and 9 mm were used in this study to investigate the effects of temperature and thickness on the drying Characteristics of pumpkin. The air velocity was maintained constant at 1 m.s-1. The results showed that as pumpkin slice thickness increased, drying time increased; however, drying temperature decreased with drying time. The data obtained from the experiment indicate only the decreasing rate period in the experimental drying curves. The drying properties have been modeled using Fick's diffusion equation, which fits all experimental data. During the drying process, the effective moisture diffusivity fluctuated between 0.203×10-9 and 2.028×10-9 m2. s^{-1}.

Keywords: Drying, Pumpkin, drying kinetic, thin layer drying

1. Introduction
Cucurbitacae is the family that includes pumpkin (*Cucurbita maxima*). According to botany, it is a squash fruit that, when ripe, is typically orange in colour. It has historically been used for both human diet and animal feed (Guiné *et al*., 2011) [3]. The term "pumpkin" is most frequently applied to Cucurbita pepo cultivars, however it is also occasionally used to refer to certain cultivars of Cucurbita maxima, C. *argyrosperma*, and C. moschata that have characteristics in common. Pumpkins are rich in antioxidants and vitamins, which have an important health-protecting effect. Pumpkin, like most vegetables, is a perishable food whose characteristics change with time. Therefore, it becomes necessary to use conservation methods that allow for preserving its properties. One of the most widely used conservation methods is drying, which is also believed to be the most important and traditional method of preserving food (Sacilik, 2007) [8]. The most popular and energy-intensive practice in the agriculture industry for preserving agricultural products is drying (Dincer, 1998) [2]. Drying is a complicated thermal process that includes mass transport phenomena and simultaneously coupled unsteady heat occurring both within and outside the product that has to be dried. The main goal of food product drying is to remove as much water as possible from the solids until chemical reactions that lead to deterioration and microbiological spoilage are greatly diminished. (Krokida *et al*., 2003) [5]. Longer shelf-life, product diversity, and substantial volume reduction are the reasons for the popularity of dried fruits and vegetables, and this could be expanded further with improvements in product quality and process applications. These improvements could increase the current degree of acceptance of dehydrated foods in the market (Maskan, 2001) [6]. The decrease of volume in food is one of the most significant physical changes that occurs throughout the drying process. Food experiences stressors in its cellular structure due to heating and water loss, which results in a reduction in size and a change in form (Mayor and Sereno, 2004) [7]. Convective drying includes two simultaneous processes: the transfer of moisture from the solid within and energy transfer from the surrounding environment. Low operating costs and simple process management are features of convective drying. One method that is frequently used to ascertain the drying kinetics of fruits and vegetables is thin-layer drying (Kadam *et al*., 2011) [4]. Heat transmission and mass transfer must occur concurrently. During these procedures, the material is completely exposed to hot air and high temperatures, speeding up the drying process.

Drying is also a critical food processing operation in the sense that many undesirable changes occur during the drying process, which reduces the quality so, any drying process is optimized to make sure that fast processing conditions lead to a product with a good enough quality and a high throughput capacity.

Pumpkin slices are generally dried using the convective method (Sojak and Glovacki, 2010) [9], because of its simplicity and low cost. Using this technique, mass and heat transfer occur simultaneously (Adiletta *et al.*, 2014) [1]. Hot air drying produces stable dehydrated products.

The goal of the current work is to ascertain pumpkin's mass transfer characteristics for air drying at temperatures between 60 °C and 80 °C, as well as to assess how drying affects a few quality parameters for the dried product.

2. Materials and Methods

2.1 Raw Material

Fresh pumpkin weighing 40±10 g on average was purchased at the nearby "Mohanpur" market in Mohanpur, West Bengal, then carefully cleaned and sorted.

2.2 Sample Preparation

Fresh Pumpkin was cut by knife into 3, 6 and 9 mm thickness. The blanching treatment was done at 95 °C by using 2% NaCl for 3 minutes and cooled at room temperature (27 °C).

2.3 Drying

Drying of pumpkin slices was carried out in the tray dryer at 60 °C, 70 °C, 80 °C and air velocity 1 $m.s^{-1}$. Drying was conducted till the samples nearly attained equilibrium moisture content and the safe moisture limit. Equilibrium moisture content was determined by continuing the drying operation up to 9-10 h.

2.4 Diffusion coefficient in dehydration

The rate of mass transfer was optimized by calculating the diffusion coefficient. Diffusion coefficient was determined by the following Fick's Law.

The rate of mass transfer was optimized by calculating the diffusion coefficient. Diffusion coefficient was calculated by the following Fick's Law.

$$\frac{(M-Me)}{(Mo-Me)} = \frac{8}{\pi^2}\sum_{n=1}^{n=\infty}\frac{1}{(2n-1)2}e^{-(2n-1)2\pi^2 Dt/L^2} \text{ ------ (1)}$$

Where,
M= Moisture content
T = Time
X = Length of the thickness among x – axis
D = Diffusion coefficient

For long time diffusion process only first team of series in above equation is considered as well as all the following terms become in significant.

$$\frac{(M-Me)}{(Mo-Me)} = \frac{8}{\pi^2}e^{-\pi^2 Dt/L^2}\text{---------(2)}$$

Where,
D= Diffusion Coefficient, ($m^2.s^{-1}$)
t = Time, (s)
L = Thickness of sample, (m)

After simplifying the expression, we get

$$\ln\left|\frac{M-Me}{Mo-Me}\right| = \ln\left|\frac{8}{\pi^2}\right| - \frac{(\pi^2 D)t}{L^2}$$

Here, slope = ð2D for a graph of ln (MR) vs. t/L^2.

Following the equation of straight line in Cartesian coordinate as, y = mx + c. Therefore, diffusion coefficient,

$$D = \frac{Slope}{\pi^2}$$

2.5 Activation energy

Activation energy can be used to determine the amount of energy needed to start diffusion at any substance. It is a function of diffusion coefficient and temperature, which can be expressed by the following Arrhenius equation,

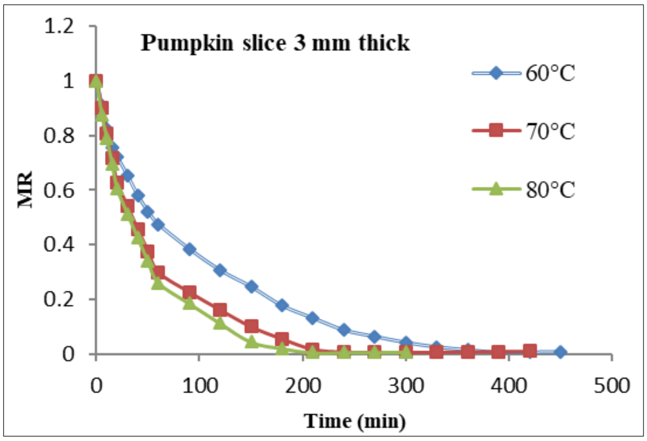
$$D = D_0 e^{-E/RT} \text{ ------ (3)}$$

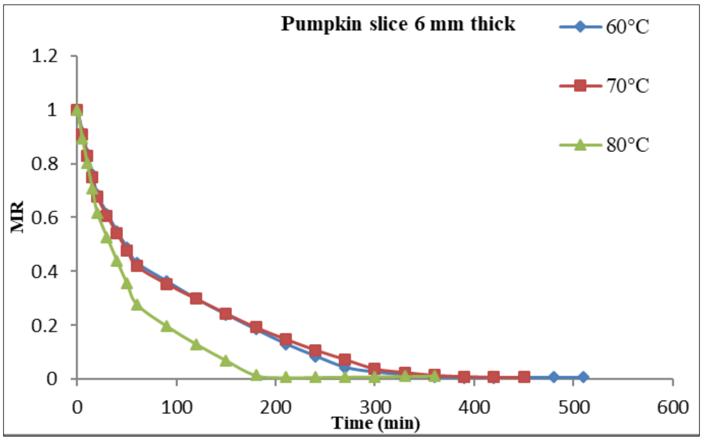
Where
D_0 = Diffusion co- efficient at infinite temperature.
E = Activation energy, (kJ. g mol^{-1}),
R = Universal gas constant, (8.134 J. g mol K^{-1})

3. Results and Discussion

3.1 Drying kinetics and estimation of diffusion and convective mass transfer coefficients

Figure 1 shows the different drying curves, expressed in terms of dimensionless moisture ratio, for the temperatures studied, for 60 °C, 70 °C and 80 °C. The graph also shows the straight lines that were fitted to the experimental points. One can see that the drying time has shortened, which is a significant energy savings. The graph also shows how the drying rate accelerates with temperature, as seen by the rising slope of the curves.





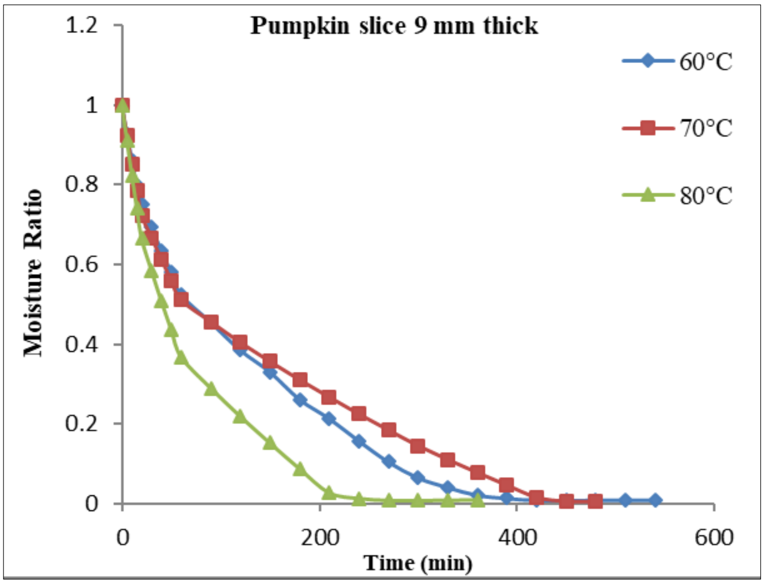


Fig 1: Moisture Ratio vs Time (min) for the thickness of 3 mm, 6 mm and 9 mm for the temperature of 60 °C, 70 °C and 80 °C, respectively

3.2 Drying rate constant
The value (k) was determined by plotting ln (MR) with time (t) for all the drying experimental conditions. By using the slope of ln (MR) and time (t) drying rate constant were calculated, by using basic equation for thin layer drying.

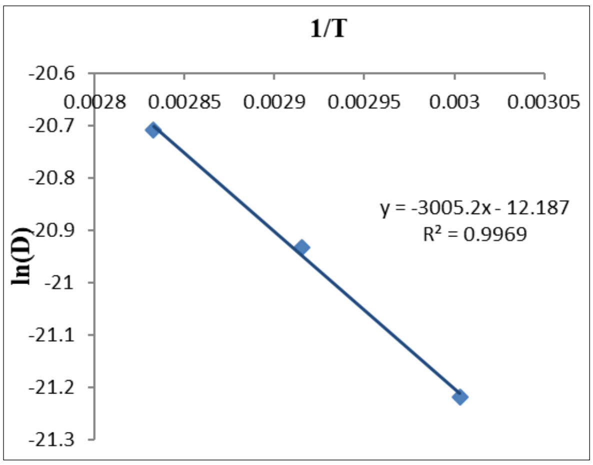
Table 1: Effective diffusion coefficient of water in pumpkin and drying rate constant

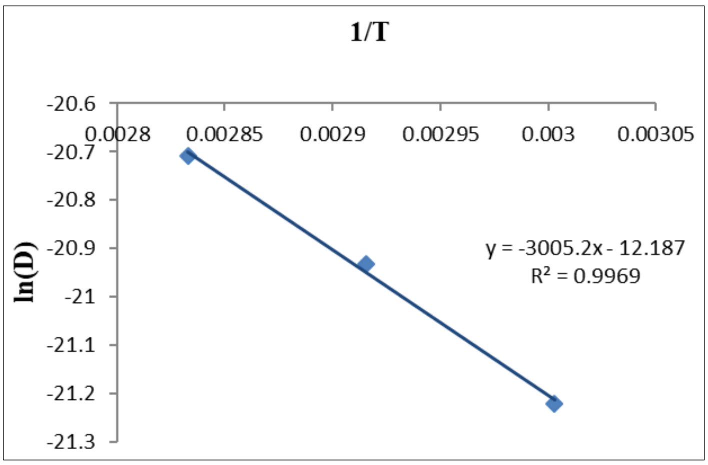
Temperature (°C)	Thickness (mm)	Diffusion Coefficient ($m^2.s^{-1}$)	Drying rate constant (h^{-1})
	3mm	0.203×10^{-9}	0.60
60°C	6mm	0.609×10^{-9}	0.45
	9mm	1.010×10^{-9}	0.40
	3mm	0.210×10^{-9}	0.98
70°C	6mm	0.810×10^{-9}	0.75
	9mm	1.014×10^{-9}	0.63
	3mm	0.304×10^{-9}	1.32
80°C	6mm	1.016×10^{-9}	1.20
	9mm	2.028×10^{-9}	1.00

Table 2: The activation energy

Thickness (mm)	Activation Energy (Ea) ($kJ.mol^{-1}$)
3	19.61 $kJ.mol^{-1}$
6	25.40 $kJ.mol^{-1}$
9	39.57 $kJ.mol^{-1}$

Diffusion coefficients were determined by using the equations 3 and 4 at different thickness (L) and temperatures. Table 1 shows the effective diffusion coefficient of water in pumpkin and drying rate constant and table 2 shows the activation energy.





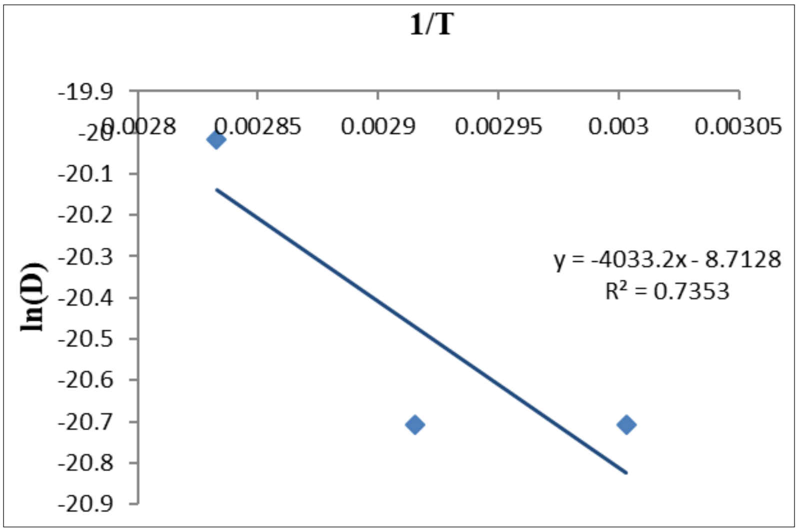


Fig 2: Effect of drying temperature on the effective diffusion coefficient of water for each thickness of pumpkin slices

The value of diffusion coefficient varied from 0.203×10^{-9} to 2.028×10^{-9} m^2. s^{-1}. The value of moisture diffusion coefficient was observed to increase with increase in temperature. The value of activation energy was observed to be 19.61 kJ. mol^{-1}, 25.40 kJ.mol^{-1}, 39.57 kJ.mol^{-1} which is increase with the thickness. The value of diffusion coefficient increases with the increase of temperature and thickness and this result confirmed with Goyal *et al*., 2011 [4].

4. Conclusion

This study looked into the effects of temperature and slice thickness on the kinetics of pumpkin drying. The advantageous impacts of raising the drying temperature and lowering slice thickness led to a shorter drying time and an increased drying rate for pumpkin slices. During the period of dropping rates, the drying process occurred. During the drying process, the effective moisture diffusivity fluctuated between 0.203×10-9 and 2.028×10-9 m^2. s^{-1}.

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