# Modelling of fluted pumpkin seed drying kinetics

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**Abstract:** In this study, the drying characteristics of fluted pumpkin seeds were examined at hot-air temperatures of 50ºC, 60ºC and 70ºC and a constant air velocity of 1.5 m $s^{-1}$. Two slicing thicknesses, 5 mm and 10 mm, were used for the experiment. The results revealed that drying took place during the falling rate period. Both the hot-air temperature and slicing thickness affected the drying rate. When the drying temperature increased from 50ºC to 70ºC, the drying time decreased from 4 hrs 20 min to 3hrs and from 5 hrs 30 min to 4 hrs 30 min for 5 mm and 10 mm slicing thicknesses respectively. The moisture ratio, drying time, effective diffusivity and activation energy were affected by drying air temperature and slice thickness. Moisture diffusivity was found to increase with a rise in drying temperature from $6.6 \times 10^{-6}$ to $28.43 \times 10^{-6}$ $m^2$ $s^{-1}$. Activation energy decreased from 6.72 to 4.02 KJ $mol^{-1}$ as slice thickness increased from 5 to 10 mm. Drying data were fitted to Page, Modified Page, Henderson & Pabis and Lewis models. All the models studied showed good fit to the drying kinetics data of fluted pumpkin seeds, with the coefficient of determination ($R^2$) above 0.92 and root mean square error (*RMSE*) below 1.0. However, the Page model gave the highest $R^2$ value (0.998), lowest *RMSE* value (0.01716) and lowest standard error of estimation value (0.0008). This shows that the Page model is the best model to describe the drying behaviour of fluted pumpkin seeds.

**Keywords**: activation energy, diffusion, drying, fluted pumpkin, moisture, Page model

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## 1 Introduction

Fluted pumpkin (*Telferia occidentalis)* is a leafy vegetable that spreads low across the ground with large lobed leaves attached on long twisting tendrils. These tendrils, on maturity, produce pods that weigh 20 kg and contain 80 seeds on the average (Schippers, 2000). Stakes are used to keep the leaves off the ground and to support pods. The leaves, stems, seeds, and roots are rich sources of food, and raw materials for industries (Akubue et al., 1980; Egbekun et al., 1998; Giami and Isichei, 1999; Ekpedeme et al., 2000; and Giami et al., 2003). The crop is widely grown in Western and Eastern Africa. Although the leaf of fluted pumpkin is considered as the essential part of the crop, and consequently widely utilized as a nutritional supplement, it has been reported that the seed contains 29.58% crude protein, 22.86% crude fat, 12.83% ash and 1609.68 KJ energy value (Effiong et al., 2009). Besides, the seed oil has high iodine value, high unsaturated fatty acids relative to palm oil, which suggests its usage as edible oil for cooking or margarine production (Agatemor, 2006). Research has shown that extract from the seed has antioxidant which protects against lipid peroxidation and cell damage in ovary tissue (Daramola et al., 2016).

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Drying has played a significant role in increasing the shelve life of agro-products by either inactivating or obliterating the microbes responsible for the deterioration of products. These microbes thrive in a moist environment, and Nwakuba et al. (2016) observed that most agro-products contain high moisture of about 70% to 90% at harvest. As a result, drying becomes an important postharvest operation to minimize postharvest losses. Over the years, many researchers have studied the behaviour of materials during drying for different crops, and such researchers include, Doymaz (2004) for carrot, Ertekin and Yaldiz (2004) for eggplant, Moreira et al. (2005) for chestnuts, Aghbashlo et al. (2008) for Barberries fruit, Saeed et al. (2008) for Roselle, Ronoh et al. (2009) Amaranth seed, Tunde-Akintunde and Afon (2010) for cassava chips, among others. The selection of drying method and experimental parameters for the thin-layer drying was based on the works of Motevali et al. (2012) and Beigi (2016).

This work aims at studying the drying characteristics of fluted pumpkin seed of different slicing thicknesses at various temperatures under forced air convection drying, and to model the drying kinetics using some drying mathematical models from the literature.

## 2 Materials and method

### 2.1 Drying experiment

Individual fluted pumpkin seeds were manually de-hulled and split into two. They were further cut into 5 mm and 10 mm slice thicknesses with a sharp knife. Three different temperature levels (50°C, 60°C and 70°C) and 1.5 m $s^{-1}$ drying air velocity were selected based on literature for the drying experiment. Forced air circulation drying oven (DHG-9030, 500 W, 220V 50 HZ, 50-200°C ± 1°C) was used for the drying. The oven used was pre-set at various temperatures and was allowed for 30 minutes to reach a steady state before introducing the samples to be dried at that temperature (Motevali et al., 2012). In the course of drying, the weights of the samples were measured at 30 mins interval using the electronic balance of 0.01 g accuracy. The drying process continued until there was no weight difference recorded.

### 2.2 Moisture ratio determination

The moisture ratio ($MR$) was calculated from the weight loss data of the samples during drying using Equation 1 as follows:

$$MR = \frac{M-M_e}{M_o - M_e} \tag{1}$$

where $M$ is the material moisture content in percentage wet basis (wb) at a time '$t$', $M_e$ is the equilibrium moisture content (wb) of the material and $M_o$ is the initial moisture content of the material (wb).

### 2.3 Effective moisture diffusivity

The effective moisture diffusivity was determined by applying Fick's second law of moisture diffusion during drying of a thin layer. With that, Equation 1 for thin slab material could be written as:

$$MR = \frac{M-M_e}{M_0-M_e} = \frac{8}{\pi^2}\left[\sum_{N=1}^{N=\infty} \frac{1}{(2N+1)^2} exp\left(\frac{-(2N+1)^2\pi^2 D_{eff}t}{4h^2}\right)\right] \tag{2}$$

Where $D_{eff}$ is the effective diffusivity ($m^2s^{-1}$), $h$ is the material thickness (m) and $t$ is the time (mins).

As the time, $t$, increases, the higher terms approach zero, and by taking $n$ = 0 Equation 2 could be reduced to (Borah et al., 2015):

$$MR = \frac{8}{\pi^2} exp\left(\frac{-\pi^2 D_{eff}t}{4h^2}\right) \tag{3}$$

This Equation 3 can be simplified further to give:

$$MR = Ae^{-kt} \tag{4}$$

Where the constants are: $A = \frac{8}{\pi^2}$ , $= \frac{6}{\pi^2}$ for slab and cylinder, respectively and $(k) = \frac{\pi^2 D_{eff}}{4h^2}$

The Equation 4 will become linear upon simplifying it thus:

$$\ln(MR) = \ln\left(\frac{M-M_e}{M_0-M_e}\right) = lnA - kt \tag{5}$$

Plotting $\ln(MR)$ versus drying time gave a straight line with a slope '$k$'. Assuming drying occurred from the top and bottom parallel faces, the thickness of the slab to be dried from one face was assumed to be half the total thickness $h$, which implies that $h = \frac{1}{2}h$. The effective moisture diffusivity of fluted pumpkin was calculated using the slope.

### 2.4 Activation energy

The activation energy for diffusion was computed using Arrhenius equation (Rafiee et al., 2008):

$$D = D_o exp\left(-\frac{E_a}{RT}\right) \tag{6}$$

Where $E_a$ is the activation energy (KJ mol$^{-1}$), $R$ is the universal gas constant, $D_o$ is effective diffusivity at 0$^o$k (m$^2$ s$^{-1}$) and T is the absolute temperature (℃).

Applying logarithm to linearize Equation 6 results to:

$$lnD = lnD_o - \frac{E_a}{R}.\frac{1}{T} \quad (7)$$

A plot of *ln D* against $\frac{1}{T}$ gives a straight-line graph in which the slope is equal to $-\frac{E_a}{R}$ from which the activation energy was obtained.

### 2.5 Drying modelling

The Page, Modified Page, Henderson & Pabis and Lewis models were used to fit to experimental data obtained from the drying process and the model equations are given below:

$$\text{Page model, } MR = \exp\left(-kt^n\right) \quad (8)$$

$$\text{Modified page, } MR = \exp\left[-(kt)^n\right] \quad (9)$$

$$\text{Henderson \& Pabis, } MR = aexp(-kt) \quad (10)$$

$$\text{Lewis model, } MR = \exp\left(-kt\right) \quad (11)$$

Where $t$ is the drying time (min), $k$ is the drying rate constant (min$^{-1}$) and $a$, $n$, are model coefficients.

The coefficient of determination ($R^2$), root mean square error (*RMSE*) and standard error of estimation (*SEE*) were used as criteria for fitting the mathematical models to the experimental data.

*RMSE* equation is given as:

$$RMSE = \left[\frac{1}{N}\sum_{i=1}^{N}\left(MR_{pre,i} - MR_{exp,i}\right)^2\right]^{\frac{1}{2}} \quad (12)$$

where RMSE is dimensionless, $MR_{pre,i}$ is the predicted moisture ratio (dimensionless), $MR_{exp,i}$ is experimental moisture ratio (dimensionless), and n is number of observations. *SEE* which has zero as its ideal value allows for comparison of the actual deviation between predicted and measured values term by term, and it is computed thus (Borah et al., 2015):

$$SEE = \sqrt{\frac{\sum_{i=1}^{N}\left(MR_{exp,i} - MR_{pre,i}\right)^2}{N - n_i}} \quad (13)$$

where SEE is dimensionless, $N$ is the number of observations, $n_i$ is the number of constants in a model, and the other coefficients remain the same as defined previously.

## 3 Results and discussions

### 3.1 Effect of drying temperature

The results of drying of the seeds at 50ºC, 60ºC and 70ºC for 5 mm and 10 mm thicknesses are presented in Figures 1 and 2. The figures revealed that moisture content decreased appreciably with an increase in temperature. This result is in agreement with the works of Abano (2010), Afolabi and Agarry (2014), Ehiem and Eke (2014) and for the drying of slices of pineapple, okra and bitter kola, respectively.

The entire drying process took place in the falling rate period as can be seen from the drying curves. This is also in line with reported works of other researchers that drying of most of agricultural products took place in the falling rate period (Ezeike and Otten, 1991; Borah et al., 2015). Also, it was observed that diffusion was the dominant mechanism of moisture movement in the drying of fluted pumpkin.

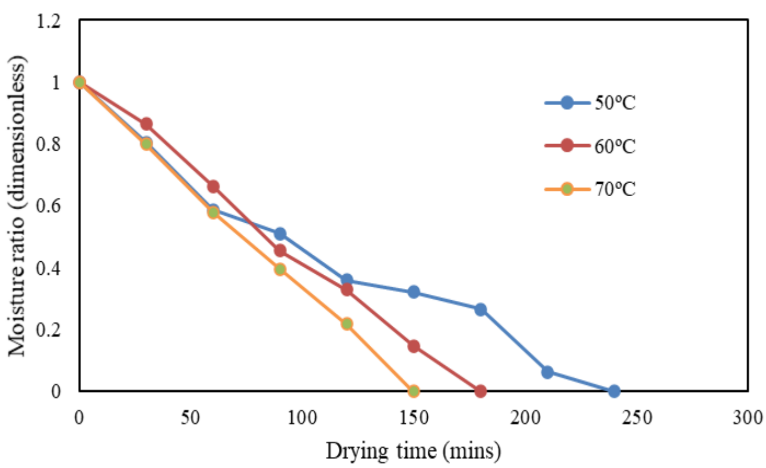


Figure 1 Drying curve of 5 mm thickness slices at various temperatures

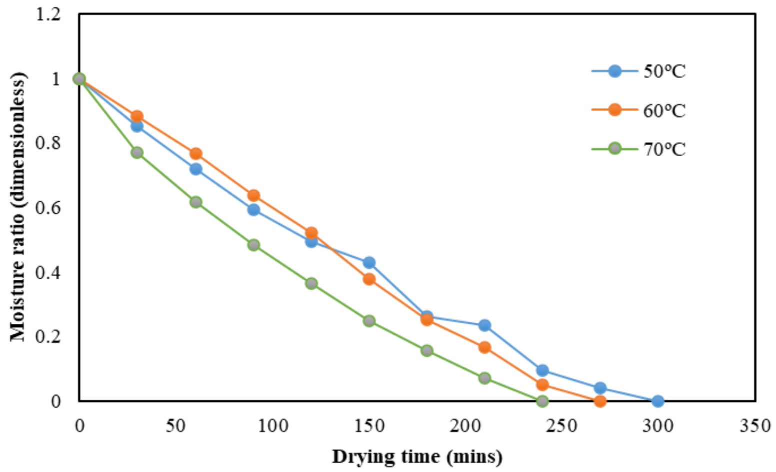


Figure 2 Drying curve of 10 mm thickness slices at various temperatures

## 3.2 Effect of slicing thickness

The results of the effect of drying thickness at 70°C, 60°C, and 50°C are shown in Figures 3, 4 and 5. The plot of moisture content against drying time revealed that at all the temperatures studied, the 5 mm slicing thickness dried faster than the 10 mm slicing thickness of the material.

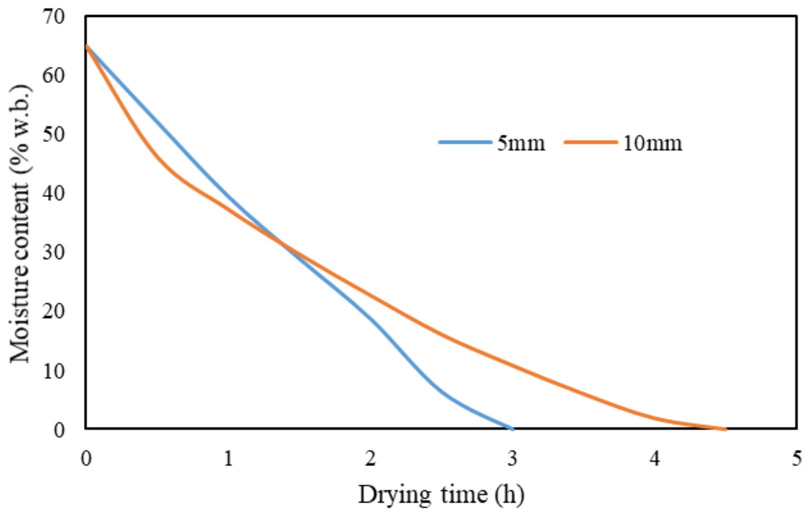


Figure 3 Effect of slicing thickness on the drying time at 70°C

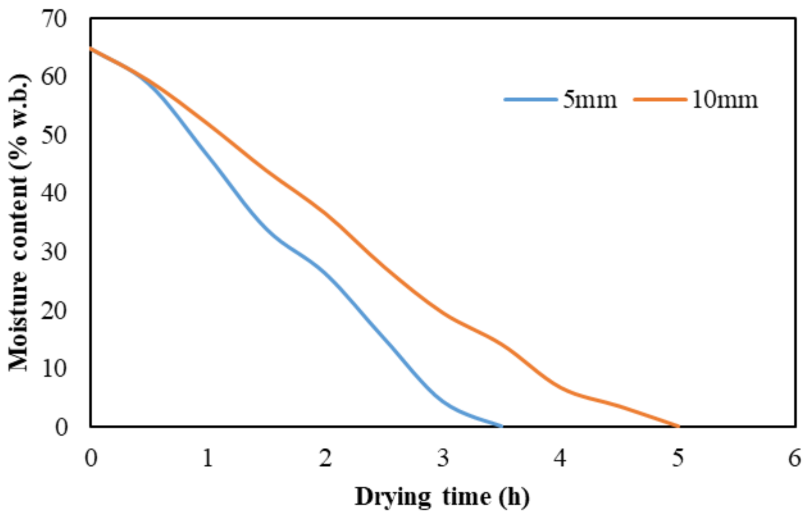


Figure 4 Effect of slicing thickness on the drying time at 60°C

The fastest drying time of 3 hrs and 4 hrs 30 min for 5 mm and 10 mm thicknesses respectively was recorded at 70°C drying temperature; whereas the slowest drying time of 4 hrs 20 min and 5 hrs 30 min for 5 mm and 10 mm thicknesses respectively, was recorded at 50°C drying temperature.

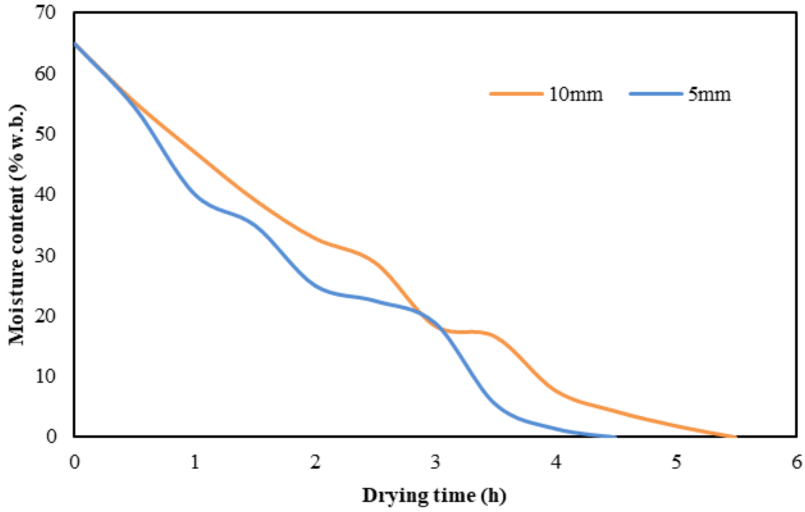


Figure 5 Effect of slicing thickness on the drying time at 50°C

### 3.3 Effective moisture diffusivity and activation energy

The effective moisture diffusion and activation energy at various temperatures are presented in Table 1. It was observed from the table that the effective diffusion increased linearly with temperature and slice thicknesses. It increased from 6.6 to 7.63 × $10^{-6}$ and 26.04 to 28.43 × $10^{-6}$ for 5mm and 10mm thicknesses, respectively. The activation energy was found to decrease from 6.72 to 4.02 KJ $mol^{-1}$ as thickness increased from 5 mm to 10 mm. The effective diffusivity of *Telferia occidentalis* is within the range of $10^{-11}$ to $10^{-6}$ $m^2\ s^{-1}$ reported by Zogzas et al. (1996) for food materials.

**Table 1 Effective diffusivities and activation energy for various slice thickness and drying temperature**

| Slice Thickness(mm) | Temperature (°C) | $D_{eff}$ ×$10^{-6}$ ($m^2\ s^{-1}$) | $E_a$ (KJ $mol^{-1}$) |
|---|---|---|---|
| | 50 | 6.6 | |
| 5 | 60 | 7.48 | 6.72 |
| | 70 | 7.63 | |
| | 50 | 26.04 | |
| 10 | 60 | 26.56 | 4.02 |
| | 70 | 28.43 | |

### 3.4 Drying modelling

The estimated parameters for the drying models are shown in Table 2. The results indicate that all the models showed good fit and they have $R^2$ values greater than 0.91, RMSE values below 1.0 and SEE values close to zero. At the drying temperature of 70°C and thickness of 5 mm, the Page model has highest $R^2$ value (0.9977), lowest *RMSE* value (0.01716) and lowest *SEE* value (0.00088). Hence, the Page model was found as the best fit model for describing the drying behaviour of fluted pumpkin seeds.

## 4 Conclusions

Thin layer drying characteristics and kinetics of fluted pumpkin seed studied at three drying air temperatures (50ºC, 60ºC and 70ºC) and two slice thicknesses (5 mm and 10 mm) showed that moisture ratio, drying time, effective diffusivity and activation energy were affected by drying air temperature and slice thickness. Effective diffusivity increased linearly from 6.6 × $10^{-6}$ to 28.43 × $10^{-6}$ $m^2\ s^{-1}$ with increased drying temperature and slicing thickness. The higher drying temperature of 70°C dried the samples in the shortest time of 3 hrs for 5 mm thickness sample and 4hrs 30 min for the 10 mm thickness sample. Drying rate was much faster during the initial high moisture period of drying in case of sliced samples. Drying of fluted pumpkin seed took place in the falling rate period. Among the models studied, the Page model was the best-fitted model to describe the drying behaviour of the seed of fluted pumpkin seed.

**Table 2 Estimated parameters for the drying models**

| | Sample | | Estimated parameters | | | | | |
|---|---|---|---|---|---|---|---|---|
| Model | thickness | Temp. | *k* | *n* | *a* | $R^2$ | *SEE* | *RMSE* |
| Page | 5mm | 50°C | 0.4269 | 1.165 | | 0.974 | 0.01715 | 0.05348 |
| | 10mm | 50°C | 0.2963 | 1.356 | | 0.9827 | 0.01606 | 0.0448 |
| | 5mm | 60°C | 0.3529 | 1.655 | | 0.9964 | 0.00184 | 0.02144 |
| | 10mm | 60°C | 0.2032 | 1.732 | | 0.9935 | 0.00588 | 0.02897 |
| | 5mm | 70°C | 0.5831 | 1.334 | | 0.9977 | 0.00088 | 0.01716 |
| | 10mm | 70°C | 0.5911 | 1.031 | | 0.9893 | 0.00731 | 0.03489 |
| Modified Page | 5mm | 50°C | 0.6781 | 0.7054 | | 0.9672 | 0.02162 | 0.06003 |
| | 10mm | 50°C | 0.5723 | 0.7165 | | 0.9524 | 0.03928 | 0.07007 |
| | 5mm | 60°C | 0.7117 | 0.6823 | | 0.9325 | 0.03409 | 0.09232 |
| | 10mm | 60°C | 1.948 | 0.1977 | | 0.9206 | 0.07126 | 0.1009 |
| | 5mm | 70°C | 14.25 | 0.04468 | | 0.9775 | 0.00878 | 0.0541 |
| | 10mm | 70°C | 0.6745 | 0.8926 | | 0.9891 | 0.00748 | 0.03531 |
| Henderson and Pabis | 5mm | 50°C | 0.4936 | | 1.027 | 0.9689 | 0.02053 | 0.0585 |
| | 10mm | 50°C | 0.4329 | | 1.051 | 0.9624 | 0.03491 | 0.06605 |
| | 5mm | 60°C | 0.5325 | | 1.072 | 0.947 | 0.02676 | 0.08179 |
| | 10mm | 60°C | 0.4274 | | 1.095 | 0.9376 | 0.05598 | 0.08943 |
| | 5mm | 70°C | 0.662 | | 1.03 | 0.985 | 0.00761 | 0.05037 |
| | 10mm | 70°C | 0.5989 | | 0.995 | 0.9891 | 0.00745 | 0.03523 |
| Lewis | 5mm | 50°C | 0.4784 | | | 0.9672 | 0.02162 | 0.05558 |
| | 10mm | 50°C | 0.4101 | | | 0.9577 | 0.03928 | 0.06606 |
| | 5mm | 60°C | 0.4856 | | | 0.9325 | 0.03409 | 0.08257 |
| | 10mm | 60°C | 0.3852 | | | 0.9206 | 0.07126 | 0.09438 |
| | 5mm | 70°C | 0.6367 | | | 0.9775 | 0.00878 | 0.04685 |
| | 10mm | 70°C | 0.6022 | | | 0.9891 | 0.00748 | 0.03269 |

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