

# Drying Characteristics of Osmotically Pretreated Red Onion Slices via Hot Air Oven

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## Abstract

The drying characteristics of osmotically pretreated red onion slices via hot air oven at different drying temperatures (40°C to 80°C) and 1.5 m/s air velocity was investigated. Fresh onion bulb was manually sliced ( $4 \pm 0.2$  mm) and pretreated in 20% osmotic solution (sucrose, salt and water in ratio 1:1:4 weight in grams) for 2 hours. Eight drying models (Page, Logarithmic, Henderson and Pabis, Newton (Lewis), Wang and Singh, Parabolic, Midilli and Prakash and Kumar) were used to optimize the goodness of fit to the experimental data. The models were compared using coefficient of determination ( $R^2$ ), chi-square ( $\chi^2$ ) and root mean square error (RMSE). Some selected functional properties of the dried onion were also examined. It took 660 min, 600 min, 390 min, 300 min and 180 min at 40°C, 50°C, 60°C, 70°C and 80°C respectively to dry dehydrated red onion from 82.14% (wet basis) moisture content to constant equilibrium moisture content. The drying took place only in a falling rate period. The Midilli model was found to best fit the experimental data compared to other models. The effective moisture diffusivity values were found to be  $1.76838 \times 10^{-10}$  m<sup>2</sup>/s for 40°C;  $1.98 \times 10^{-10}$  m<sup>2</sup>/s for 50°C;  $3.11 \times 10^{-10}$  m<sup>2</sup>/s for 60°C;  $4.26 \times 10^{-10}$  m<sup>2</sup>/s for 70°C and  $7.03 \times 10^{-10}$  m<sup>2</sup>/s for 80°C respectively. The activation energy ( $E_a$ ) was found to be 29.67 KJ/mol. The results of these measures have confirmed the consistency of the developed model to describe satisfactorily the drying characteristics of red onion slices at different drying temperature.

**Keywords:** Red onion; Osmotic pretreatment; Drying characteristics; Hot air oven

## Introduction

Onion (*Allium cepa* L.) is a famous vegetable commodity grown all over the world and consumed in the various forms. According to the United Nations Food and Agricultural Organizations, the world total onion production is 8.90 million tonnes. India was the leading country with an estimated production of 5.51 million tonnes followed by Nigeria with an estimation of 1.98 million tonnes [1]. Onion is an indispensable item in every kitchen as condiment and vegetable. It is has been widely used as seasonings, foods (either in raw form or dehydrated form to add flavour and taste) and for medical uses since the ancient times [2]. With more emphasis on disease prevention than cure, there has been an increased interest by scientists on the high content of polyphenolic flavonoids in onions [3]. Onion and leek are high in flavonoids [4]. Even though the onion has high nutritional value, it is largely consumed for its unique flavour and its ability to improve the flavour of other foods [5]. Sixty-two percent of the world's production is from Asiatic countries. India is the world's second largest producer of onion [6] while it was the third most popular in South Africa, after potatoes being first and tomatoes being second. In Nigeria, onion is the second most important vegetable after tomato. Its main production is from the Northern part of the country where considerable quantity is produced annually [7].

Onion has special qualities, which add to taste and flavour to food and hence it is mainly used in India for cuisine and culinary preparations. Besides adding a delicious taste and flavour, onion serves as an appetizer, food digester and health promoter. It also serves as a good medicinal compound for cataract, cardiovascular disease and cancer due to its hypocholesterolemic, thrombolitic and antioxidant effects as reported by Block [8]. Onions are highly perishables, since they are extremely sensitive to heat and humidity thus, they require much care from harvest to transport, with special attention for packing and storage. Onions are available in large quantity during the harvesting season of which Most of them are not utilized properly due to oversupply in peak season, lack of adequate processing technology, preservation, adequate transportation

and marketing facilities. The losses include decay or rotting, sprouting, physiological loss of weight, splitting of bulbs, discoloration, shrinkage, descaling and rooting. Dehydration processes offer an alternative way of using onion for consumption and the dehydration of onions like other vegetables have been practiced for many years as a means of preservation [9]. Dried onion products are produced in several forms such as; faked, minced, chopped and powdered [2]. Kaymak-Ertekin and Gedik [10] reported that dehydrated onion has become a standard food ingredient in a wide range of food products such as ketchup, soups, salad dressings, sausage and meat products, potato chips, crackers, and many other convenience foods.

In spite of these, Onion is mainly known for its characteristic flavour which adds a delicious taste to almost all the food preparations. Since ancient times, onion has been mainly used for its cuisine and culinary properties. Therefore, the main challenge has been to preserve the pungent taste, flavour, and colour of onion along with the desired moisture content as it is responsible for most of the deteriorative microbial reactions, for safe storage life and rehydration ratio during dehydration process [11]. Hot air dehydration has been largely employed to preserve fruits and vegetables. In order to obtain high quality dehydrated food, there is a need to modify this drying method so as to limit its adverse influence, especially on flavour, colour, nutrients and fruit tissue. One possible solution is to apply osmotic dehydration,

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which involves the immersion of fruit in osmotic solution resulting in the removal of water from tissue, and replacing it with soluble solids as a pretreatment [12,13].

Osmotic dehydration is the most reported pretreatment used prior to air-drying [14,15]. It removes water from the fruit or vegetable up to a certain level, which is still high for food preservation so that this process must be followed by another process in order to lower even more the fruit water content [16]. It is a useful technique that involves the immersion of the fruit in a hypertonic aqueous solution leading to the loss of water through the cell wall membranes of the fruit and subsequent flow along the inter-cellular space before diffusing into the solution [17]. As a partial dehydration process, osmosis may be regarded as a simultaneous water and solute diffusion operation, wherein the sample incurs a gain of solids and a simultaneous loss of moisture [18]. The shelf life quality of the final product is better than without such treatment due to the increase in sugar/acid ratio, the improvement in texture and the stability of the colour pigment during storage [14]. Osmotic dehydration preceding air drying decreases colour changes and increases flavour retention in dried fruits and vegetables [15]. The resulting product has generally better quality than the dried one without pretreatment. Ade-Omowaye et al. [19] also reported that osmotic pretreatment reduced heat damage, improved textural quality, vitamin retention, flavour enhancement and colour stabilization.

In order to successfully transfer knowledge acquired experimentally from studies on food dehydration into industrial applications, mathematical modelling of drying kinetics is required. Moreover, a mathematical model is an important tool used to optimize operating parameters and to predict performance of a drying system [20]. Numerous mathematical models, empirical and semi-empirical, have been proposed to estimate the drying characteristics of agricultural products [21]. These simple models, also known as thin layer models, allow prediction of mass transfer during dehydration and are applied to simulate drying curves under similar conditions [22,23]. Many researches have been conducted on the mathematical modeling and experimental studies on thin layer drying processes of various vegetables and fruits, such as green bean [24,25] red pepper [26], mint leaves [27], tarragon [28], potato [29], chilli pepper [30], carrot [31], citrus aurantium leaves [32], tomato slice [33-35] and Onion slice [16]. However, few reports have focused on the evaluation of a suitable drying model for describing the drying kinetic of osmotically pretreated red onion varieties. Therefore, the aim of this study was to investigate the influence of pretreatments and drying air temperature on the drying kinetic of osmotically pretreated red onion varieties.

## Materials and Methods

### Raw material preparation

The fresh Onion bulbs (*Allium cepa*) (red species) used for this study were purchased from Jimeta modern market Yola, Adamawa State, Nigeria. The onion bulbs was stored in a storage chamber at a temperature of 4°C ± 1°C and 70% air relative humidity to allow it equilibrate with ambient temperature. The fresh red onion bulbs were thoroughly washed with tap water to remove adhering debris, hand peeled and cut into circular slices (direction perpendicular to the vertical axis) of thickness equal to 4 ± 0.5 mm using a manual stainless knife. Initial moisture content of the sample was determined using the oven drying method according to the AOAC [36] method (number 934.01) and found to be 82.14 ± 0.28 g water per 100 g sample.

### Osmotic dehydration of onion

Osmotic solution of 20% Brix concentration was prepared using the equation 1 as described by Ade-Omowaye et al. [19]. One (1) Kg of onion was immersed in a beaker containing the osmotic solution (sucrose, salt and water in ratio 1:1:4 weight in grams) for 2 hours. This solution was stirred at interval of fifteen minute (15 min).

$$\frac{x}{x+y} = z\% \quad (1)$$

Where,

X: Weight of sugar and salt,

Y: Weight of solvent i.e., distilled water,

Z: Percentage of the weight/weight of °Brix.

### Drying procedure

Hot air oven (Model: TO008GA-34, AKAI-Tokoyo, Japan) was used for the drying. The osmotically pre-treated onion slices were divided into five equal portions. The first portion was dried at 40°C air temperature and a constant 1.5 m/s airflow velocity. The moisture loss was recorded in 5 min interval for an hour, then the weighing interval was increased to 10 min for next one hour the further readings was taken at 15 min interval by a digital balance of 0.01 g accuracy. The drying was continue till constant weight is reached and the drying was replicated three times. The drying procedure was repeated for the air-drying temperature of 50°C, 60°C, 70°C and 80°C and 1.5 m/s constant airflow velocity.

### Mathematical modelling

**Determination of moisture ratio:** The moisture ratio of onions slices dried at 40°C, 50°C, 60°C, 70°C and 80°C air temperature at a given time, t was calculated using a relationship;

$$\text{Moisture ratio (MR)} = \frac{M_t - M_e}{M_i - M_e} = e^{-kt} \quad (2)$$

Where,

$M_i$  and  $M_e$  are the initial and equilibrium dry basis moisture contents percentage

$M_t$  is dry basis moisture content at any time 't'

$k$  is the drying rate constant per minute

$t$  is the drying time (min).

The values of  $M_e$  are relatively small compared to  $M_i$  and  $M_t$ , where error implied in the simplification is negligible. Drying curves was obtained for the onions. The experimental moisture ratio versus drying time data was fitted in eight thin layer drying models (Page, Logarithmic, Henderson and Pabis, Newton (Lewis), Wang and Singh, Parabolic, Midilli et al. [25] widely used to describe the drying characteristics of most food products and the best model selected [37,38] (Table 1). The acceptability of the model was determined by the coefficient of determination  $R^2$ . 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 (RMSE). For quality fit,  $R^2$  value should be higher, close to one, and  $\chi^2$  and RSME values should be lower [34,39].

The statistical parameters were calculated by using the following relationships;

Model name	Model equation	References
Wang and Singh	MR=1 + kt + ct <sup>2</sup>	Hussein et al. [34], Wang and Singh [60]
Prakash and Kumar	MR= at <sup>3</sup> + bt <sup>2</sup> + ct + d	Prakash and Kumar [61]
Page	MR=exp(-kt <sup>n</sup> )	Hussein et al. [34], Hassan-Beygi et al. [62]
Logarithmic	MR=a exp(-kt) + b	Tunde-Akintunde and Oke [30], Khazaei et al. [63]
Henderson and Pabis	MR=a exp(-kt)	Tunde-Akintunde and Oke [52], Shittu and Raji [64]
Newton (Lewis)	MR=exp(-kt)	Tunde-Akintunde et al. [30], Tunde-Akintunde and Oke [52]
Parabolic	MR=a + kt + ct <sup>2</sup>	Hussein et al. [34], Tunde-Akintunde and Oke [52]
Midilli et al.	MR= a exp(-kt <sup>n</sup> ) + bt	Midilli et al. [25]

Table 1: Mathematical models fitted to red onion slices drying curves.

$$x^2 = \frac{[\sum_{i=1}^N (MR_{pre,i} - MR_{exp,i})^2]}{N-n} \quad (3)$$

$$RSME = \sqrt{\frac{1}{N} \sum_{i=1}^N (MR_{pre,i} - MR_{pre,i})^2} \quad (4)$$

**Determination of moisture effective diffusivities:** In drying, diffusivity is used to indicate the flow of moisture out of material. In falling rate period of drying, moisture transfer within the food is mainly by molecular diffusion. Moisture diffusivity is influenced by shrinkage, case hardening during drying, moisture content and temperature of material. The falling rate period of biological materials is best described by Fick's second law of diffusion [40]. Uniform initial moisture distribution throughout the sample, negligible external resistance to movement and onion slices releasing the moisture from top as well as from bottom surface are assumed. The solution to this equation developed by Crank [40] can be applied for onion slices:

$$MR = \frac{\theta}{\pi^2} \sum_{n=0}^{\infty} \frac{1}{(2n+1)^2} \exp\left(-\frac{(2n+1)^2 D_{eff} \pi^2}{4l^2} t\right) \quad (5)$$

Where;

$D_{eff}$ : Effective moisture diffusivity, m<sup>2</sup>/s

T: Drying time, s

L: Half thickness of a thin layer sample, m; and n is a positive integer

For long drying time, only the first term of equation 5 is significant [41] and then the solution becomes;

$$MR = \frac{\theta}{\pi^2} \exp\left(-\frac{D_{eff} \pi^2}{4l^2} t\right) \quad (6)$$

This could be further simplified to a straight-line equation as;

$$\ln(MR) = \ln\left(\frac{\theta}{\pi^2}\right) - \left(\frac{D_{eff} \pi^2}{4l^2} t\right) \quad (7)$$

The effective moisture diffusivity values were determined by plotting experimental drying data in terms of ln (MR) versus drying time t. A plot of ln (MR) versus drying time gives a straight line with a slope;

$$slope = -\frac{D_{eff} \pi^2}{4l^2} \quad (8)$$

Knowing the onions slice thickness and the slope from the above plot, the moisture diffusivity ( $D_{eff}$ ) will be calculated.

**Determination of activation energy:** The dependence of the effective diffusivity on the different drying temperature can be predicted

appropriately using the Arrhenius equation which is given by Simal, Femenia, Carcel and Rossello [42]:

$$D_{eff} = D_o \exp\left(-\frac{E_a}{R(T+273.15)}\right) \quad (9)$$

Where  $D_{eff}$  is the effective moisture diffusivity in m<sup>2</sup>/s,  $D_o$  is the pre-exponential factor of Arrhenius equation or maximum diffusion coefficient (at infinite temperature) in m<sup>2</sup>/s,  $E_a$  is the activation energy in kJ/mol, R is the universal gas constant in kJ/mol K, and T is temperature in °C.

Linearizing the equation gives

$$\ln D_{eff} = \left(-\frac{1}{R(T+273.15)}\right) E_a + \ln D_o \quad (10)$$

The activation  $E_a$  was obtained by plotting  $\ln D_{eff}$  against

$$\left(-\frac{1}{R(T+273.15)}\right) \quad (11)$$

## Results and Discussion

### Drying curves of red onion sliced

The change in moisture content of red onion slices with drying time in hot air oven at different drying temperatures (40°C, 50°C, 60°C, 70°C and 80°C) was presented in Figure 1. It was observed that as the drying temperatures increases the drying time reduced. The drying time reached the equilibrium moisture content at 660, 600, 390, 300 and 180 min for 40°C, 50°C, 60°C, 70°C and 80°C, respectively. The moisture content of onion slices decreased exponentially with elapsed drying time. That is, as the air temperature increased, other drying conditions being same, the drying curves became steeper indicating higher moisture removal rates which thus resulted into substantial decrease in drying time. Similar result was reported by Madamba et al. [43], at the beginning, the moisture content reduced rapidly and then decreased slowly with increase in drying time. Drying temperature has an important effect on drying at higher temperature, due to the quick removal of moisture, the drying time was shorter. Similar observations were reported for drying of garlic slices [43], onion slices [16,44], egg plants [45] and tomato slice [46]. The osmotic solution also resulted into removal of substantial amount of moisture from the onion slices thus, decrease the drying time. It was obvious from the results that the initial osmotic dehydration shortens drying time depending on the kind of osmotic active substance used, the time of osmotic pre-concentration and final water content of the dried product [47]. Baroni and Hubinger [48] reported that the drying time of onions can be reduced to less than half by introducing an hour of osmotic dehydration in a salt solution.

### Effective moisture diffusivity of red dried onion slices

It was reported that the mechanisms of mass transfer in food are

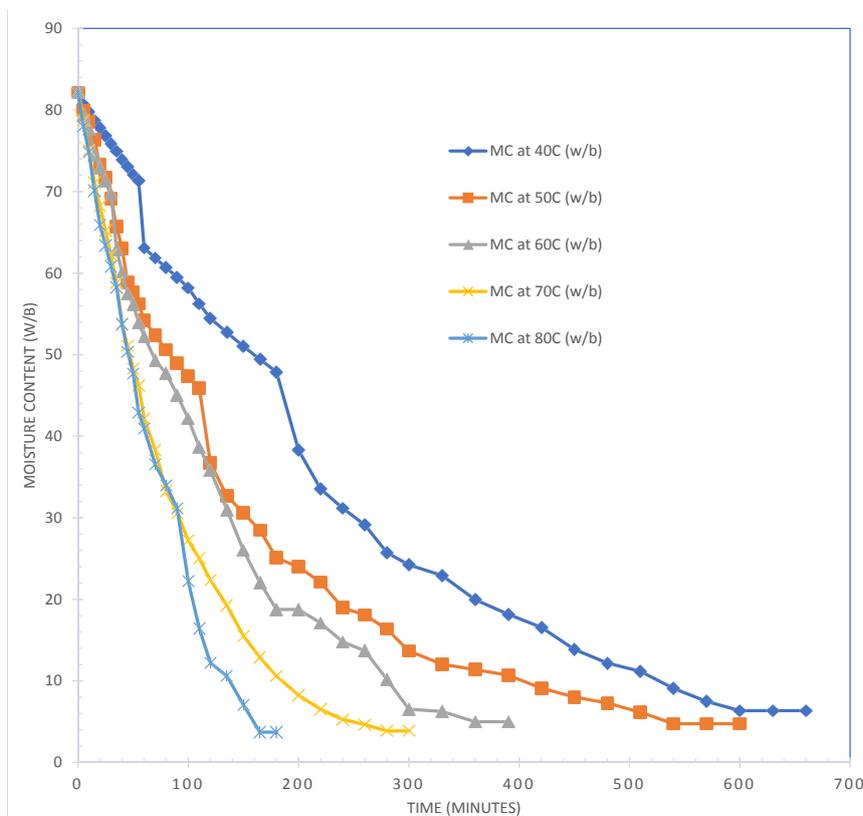


Figure 1: The drying curve of red onion slices.

complex in nature [46]. The water migrates from the inside of the product to the surface under the effect of various mechanisms which can be combined. In this study, only a falling rate drying period, which resulted in shrinkage of the dried onion slices, was observed. Thus, the main mechanism of the water transport for the onion slices is considered as diffusive type. The method of slopes as shown in eq. (7) was used to calculate the effective moisture diffusivity coefficient. Slope of graphs of  $\ln(MR)$  versus time for the experimental drying were determined. The effective moisture diffusivity values were found to be  $1.77 \times 10^{-10} \text{ m}^2/\text{s}$  for  $40^\circ\text{C}$ ,  $1.98 \times 10^{-10} \text{ m}^2/\text{s}$  for  $50^\circ\text{C}$ ,  $3.11 \times 10^{-10} \text{ m}^2/\text{s}$  for  $60^\circ\text{C}$ ,  $4.26 \times 10^{-10} \text{ m}^2/\text{s}$  for  $70^\circ\text{C}$  and  $7.03 \times 10^{-10} \text{ m}^2/\text{s}$  for  $80^\circ\text{C}$ . This results is similar to  $0.83 \times 10^{-10}$  to  $1.30 \times 10^{-10} \text{ m}^2/\text{s}$  reported by Revaskar et al. [16] for osmotically pretreated onion slices in the drying air temperature range of  $50^\circ\text{C}$ - $70^\circ\text{C}$  but slightly faster than those of  $3.65 \times 10^{-9}$  to  $9.53 \times 10^{-9} \text{ m}^2/\text{s}$  reported by Mota et al. [49] for onion slices in the drying air temperature range of  $30^\circ\text{C}$ - $60^\circ\text{C}$  and  $3.49 \times 10^{-8}$  to  $9.44 \times 10^{-8} \text{ m}^2/\text{s}$  reported by Demiray et al. [2] onion slices in the drying air temperature range of  $50^\circ\text{C}$ - $70^\circ\text{C}$ . However, the  $D_{\text{eff}}$  values obtained for red onion slices in this study lie within the general range of  $10^{-12}$  to  $10^{-8} \text{ m}^2/\text{s}$  for drying agricultural materials [33,49].

The drying temperature has a significant effect on the internal mass transfer during drying since the higher the drying temperature, the shorter the time of drying. Diffusion of moisture from the internal regions to the surface occurs. This is because surface water removal is faster at higher temperature [50-52]. Revaskar et al. [16] reported that

effective moisture diffusivity with osmotic pretreatment can increase due to loosening of the surface cellular structure and leaching of some soluble components of the external cell layers of onion slices during soaking in osmotic solution.

#### Modeling on drying characteristic of red onions slices

The summary of model parameters of the eight thin layer drying models obtained from the non-linear regression of the models are shown in Table 2. The statistical results obtained from the non-linear regression of the models which include the criteria for evaluating goodness: coefficient of determination ( $R^2$ ), the reduced chi-square ( $\chi^2$ ), and root mean square error (RMSE). The selection of the best model for predicting the drying characteristics of red onions slice is based on the model having the highest  $R^2$  value and lowest  $\chi^2$  and RMSE value [33]. The overall value of  $R^2$  (0.9999) obtained from the Midilli model is higher than those overall correlation coefficients that was found for Page (0.9980), Logarithmic (0.994), Henderson and Pabis (0.988), Newton (0.983), Wang and Singh (0.725), Parabolic (0.9000) and Prakash and Kumar models (0.969). Thus, the Midilli model best fitted to the experimental dimensionless moisture content data followed by the Page model. However, considering the model that had the lowest  $\chi^2$  and RMSE values, Page model ( $\chi^2=0.000134$  and  $\text{RMSE}=0.011354$ ) best fitted to the dimensionless moisture content data followed by Midilli ( $\chi^2=0.000273$  and  $\text{RMSE}=0.016165$ ), Henderson and Paris ( $\chi^2=0.000829$  and  $\text{RMSE}=0.028291$ ), Logarithmic ( $\chi^2=0.00086$  and  $\text{RMSE}=0.028811$ ), Newton ( $\chi^2=0.001124$  and  $\text{RMSE}=0.032948$ ), Prakash Kumar ( $\chi^2=0.00304$  and  $\text{RMSE}=0.054463$ ), Parabolic ( $\chi^2=0.009297$  and  $\text{RMSE}=0.09524$ ) and Wang and Singh ( $\chi^2=0.025331$

Model	Constant	Temperature	R <sup>2</sup>	χ <sup>2</sup>	RSME
Page	k=0.025; n=0.83	40	0.990	0.000891	0.029113
	k=0.054; n=0.760	50	0.989	0.000754	0.027112
	k=0.056; n=0.774	60	0.992	0.000607	0.024247
	k=0.074; n=0.778	70	0.998	0.000134	0.011354
	k=0.079; n=0.774	80	0.998	0.000142	0.011661
Logarithmic	k=0.012; a=0.927; b=0.038	40	0.989	0.000932	0.030154
	k=0.023; a=0.925; b=0.042	50	0.988	0.000955	0.030506
	k=0.026; a=0.917; b=0.043	60	0.989	0.001304	0.035544
	k=0.035; a=0.921; b=0.032	70	0.994	0.00086	0.028811
	k=0.037; a=0.910; b=0.035	80	0.990	0.0016675	0.040022
Henderson and Pabis	k=0.011; a=0.945	40	0.984	0.001375	0.036624
	k=0.020; a=0.938	50	0.976	0.001646	0.040045
	k=0.022; a=0.932	60	0.980	0.001424	0.037147
	k=0.031; a=0.933	70	0.988	0.000829	0.028291
	k=0.033; a=0.923	80	0.986	0.001006	0.031021
Newton (Lewis)	k=0.012	40	0.981	0.001672	0.040383
	k=0.022	50	0.973	0.001883	0.04283
	k=0.024	60	0.975	0.001761	0.041306
	k=0.034	70	0.983	0.001124	0.032948
	k=0.036	80	0.979	0.001489	0.037745
Wang and Singh	k=-0.006; c=6.706×10 <sup>-6</sup>	40	0.714	0.025331	0.157205
	k=-0.007; c=9.558×10 <sup>-6</sup>	50	0.190	0.074544	0.269504
	k=-0.010; c=2.082×10 <sup>-5</sup>	60	0.477	1.338799	1.138842
	k=-0.013; c=3.560×10 <sup>-5</sup>	70	0.401	8.106664	2.7977
	k=-0.019; c=7.979×10 <sup>-5</sup>	80	0.725	102.368	9.895311
Parabolic	k=-0.004; c=4.271×10 <sup>-6</sup> ; a=0.755	40	0.895	0.009297	0.09524
	k=-0.004; c=4.831×10 <sup>-6</sup> ; a=0.608	50	0.774	0.019587	0.138148
	k=-0.006; c=1.155×10 <sup>-5</sup> ; a=0.673	60	0.835	0.359334	0.590004
	k=-0.007; c=1.929×10 <sup>-5</sup> ; a=0.645	70	0.817	2.173204	1.448539
	k=-0.012; c=4.974×10 <sup>-5</sup> ; a=0.745	80	0.900	37.21861	5.966608
Midilli et al.	k=0.025; b=3.237 × 10 <sup>-5</sup> ; a=1.015; n=0.834	40	0.991	0.000788	0.027734
	k=0.058; b=4.355 × 10 <sup>-5</sup> ; a=1.036; n=0.755	50	0.992	0.000627	0.024713
	k=0.056; b=5.796 × 10 <sup>-5</sup> ; a=1.017; n=0.784	60	0.993	0.00082	0.028182
	k=0.073; b=5.080 × 10 <sup>-5</sup> ; a=1.010; n=0.786	70	0.999	0.000376	0.019055
	k=0.083; b=-3.158 × 10 <sup>-5</sup> ; a=1.006; n=0.761	80	0.998	0.000273	0.016165
Prakash and Kumar	a=-1.385 × 10 <sup>-8</sup> ; b=1.717 × 10 <sup>-5</sup> ; c=-0.007; d=0.869	40	0.966	0.00304	0.054463
	a=-2.169 × 10 <sup>-8</sup> ; b=2.321 × 10 <sup>-5</sup> ; c=-0.008; d=0.743	50	0.897	0.011196	0.104446
	a=-7.142 × 10 <sup>-8</sup> ; b=5.118 × 10 <sup>-5</sup> ; c=-0.011; d=0.811	60	0.939	1.882918	1.350584
	a=-1.605 × 10 <sup>-7</sup> ; b=8.830 × 10 <sup>-5</sup> ; c=-0.015; d=0.794	70	0.936	27.3236	5.136283
	a=-5.542 × 10 <sup>-7</sup> ; b=0.000; c=-0.022; d=0.868	80	0.969	1101.916	32.46547

Table 2: Estimated parameters and comparison criteria of moisture ratio of red onion slices.

and RMSE=0.157205) models. Thus, from the above results, it was observed that the Midilli model satisfactorily describes the drying characteristic of osmotically pretreated red onion slices dried in a hot air oven.

The experimental and the predicted data values using Midilli model for moisture ratios of osmotically pretreated red onion slices dried in a hot air oven is shown in Figure 2. The established model provided a very good conformity between the experimental data and the predicted moisture ratios of the osmotically pretreated red onion slices. It was observed that the predicted data are banded around the ideal trend line indicating the suitability of the model in predicting the drying behavior of osmotically pretreated red onion slices dried in a hot air oven.

### Activation energy

The activation energy was obtained from a graph of Ln D versus the reciprocal of the absolute temperature 1/Tabs (Figure 3) and it was

calculated using eq. 10. The activation energy (Ea) for diffusion of moisture for red onion was calculated and found to be 29.67 KJ/mol. Similar results of 26.83 KJ/mol by Babu et al. [53] and 26.40 KJ/mol by Mota et al. [49] were reported for the diffusion of water from onion. The activation energy is determined by the forms in which water exists in foods, namely surface absorption and chemical absorption. The activation energy is a measure of the temperature sensitivity of D<sub>eff</sub> and it is the energy needed to initiate the moisture diffusion within the seed [54]. This activation energy is in reasonable agreement with the data presented by several other authors, for example 27.61 kJ/mol for corn [55], 28.40 kJ/mol for green peas [56], 28.36 kJ/mol for carrot [57], 30.79 kJ/mol for pistachio nut [57,58] and 28.15 kJ/mol for tiger nut seed [52]. The differences in activation energy value vary from product to product as attributed due to product characteristics and process parameters as noted by Villota and Hawkes [59]. However, the activation energy obtained for each variety is within the general

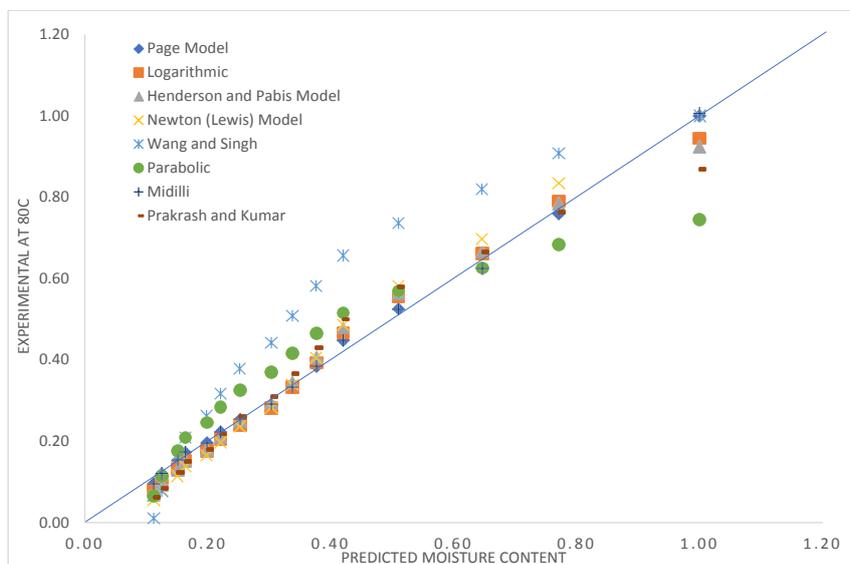


Figure 2: Experimental and predicted drying curves for osmotically pretreated red onion slices at 80°C.

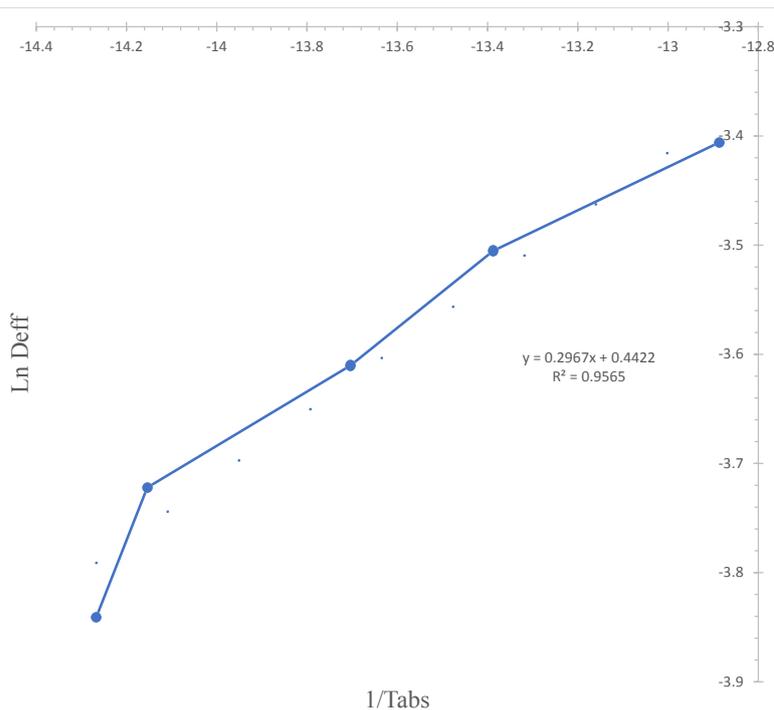


Figure 3: Activation energy of osmotically pretreated red onion slices.

range of 12.7-110 kJ/mol [59] for most agricultural and food materials as presented by several other reports [60-64].

## Conclusion

The drying characteristic of osmotically pretreated red onion slices via hot air oven at 40°C to 80°C drying temperature and 1.5 m/s air velocity was investigated in this study. The initial osmotic dehydration resulted into removal of substantial amount of moisture from the onion slices thereby shorten the drying time. The entire drying process occurred

in falling rate period and constant rate period was not observed. Eight drying models (Page, Logarithmic, Henderson and Pabis, Newton (Lewis), Wang and Singh, Parabolic, Midilli, Prakash and Kumar) were used to optimize the goodness of fit to the experimental data. The Midilli model was found to best fit the experimental data compared to other models. The effective moisture diffusivity values were found to be  $1.76838 \times 10^{-10} \text{ m}^2/\text{s}$  for 40°C,  $1.98 \times 10^{-10} \text{ m}^2/\text{s}$  for 50°C,  $3.11 \times 10^{-10} \text{ m}^2/\text{s}$  for 60°C,  $4.26 \times 10^{-10} \text{ m}^2/\text{s}$  for 70°C and  $7.03 \times 10^{-10} \text{ m}^2/\text{s}$  for 80°C respectively. The activation energy ( $E_a$ ) was found to be 29.67 KJ/mol.

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