

## AN EXPERIMENTAL STUDY OF SHATKORA (*CITRUS MACROPTERA*) IN A TRAY DRYER : EFFECT ON DRYING KINETICS AND PRODUCT QUALITY

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### ABSTRACT

*Citrus macroptera* is a citrus fruit locally known as Shatkora and the fruit of this plant were used for various purposes especially for cooking and also as an odorant in perfume industries. In this research work, Shatkora peel was dried using a laboratory scale tray dryer. The experimental work was conducted at an inlet temperature of 40–60°C and velocities from 0.5–0.9 m/s. Besides, the thickness of the layer was varied between 2–10 mm. The results demonstrated that the rate of drying was increased accordingly with rise in both air temperature and air velocity however a decreased in layer thickness was noticed. At high air temperature, moisture content of solid achieved equilibrium state within short period of time. On the other hand, moisture diffusivity of Shatkora was evaluated by applying Fick's second law and the value was varied from  $1.78 \times 10^{-8}$  to  $2.83 \times 10^{-7}$ . In addition, activation energy was determined by using Arrhenius type relation and 19.70 kJ/mol was obtained.

**Keywords:** Drying; Shatkora; Drying rate; Moisture content; Diffusion coefficient.

### 1.0 INTRODUCTION

*Citrus macroptera* also generally known as Sat kara or Shatkora is the most famous and costly citrus fruits cultivated all over Sylhet areas of Bangladesh. The semi wild species are majorly used for medicinal purpose by local tribes of Assam, India (Nongalleima *et al.*, 2017). In Bangladesh, both green and mature fruits are added as main ingredients for cooking and also to make pickles. Moreover, the sweet flavor of fruits created by essential oil of flavedo parts can be applied for flavoring purposes in perfume

industries. Annually, Bangladesh earns huge profits by exporting these fruits particularly to UK, USA and Middle East countries. On the other hand, due to high moisture content (approximately 75% w/w) of the fruits at harvest, it is difficult to be preserved under atmospheric conditions (20–25°C) for more than couple of days. In spite of the fact that Shatkora can be preserved in refrigerator but in Bangladesh very smaller number of population has access to have refrigerator. Therefore, the easiest and cheapest preservation technique to keep this fruits for a longer period of time is through drying.

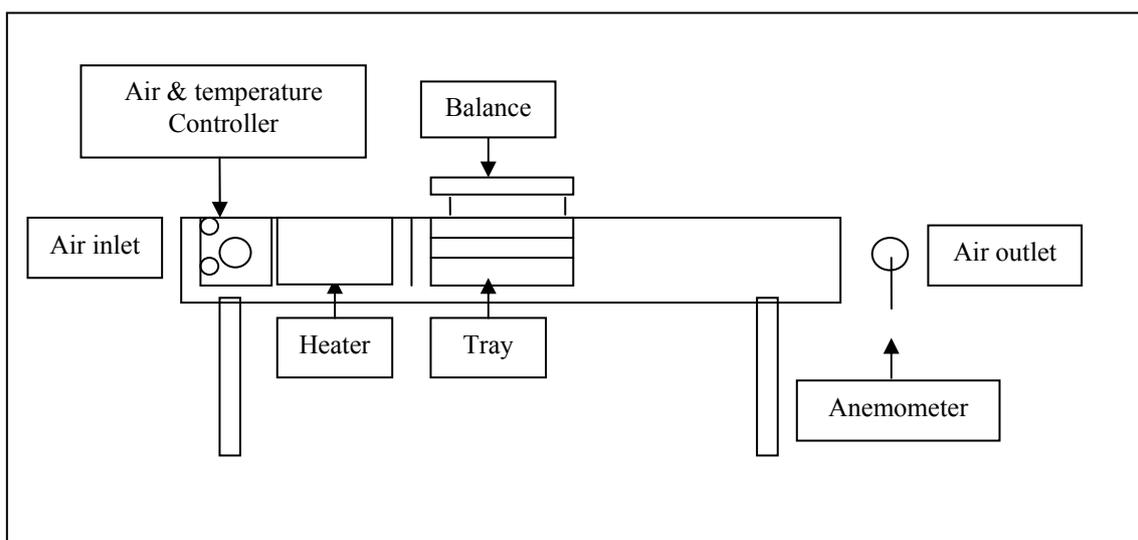
Drying is depicted as one of the best methods to remove moisture in which transferring both mass and heat simultaneously. This method also known to be a conventional technique for preserving foods, which guaranteed longer shelf-life, lighter load for transportation as well as only small space are required for storage (Ertekin & Yaldiz, 2004). In contradiction with fresh vegetables which could sustain for only couple of days under atmospheric conditions, dry items are possible to be kept for a considerable length of time or even years without losing any appreciable nutrients. Bulk weight also can be reduced by drying methods, thus facilitating ease of transportation. At times, drying may prompt an extensive decrease in volume and consequently reduced the space required for storage.

Various factors for instance batch size, properties of the materials used, moisture contents of the products, climate changes, and the demand for the dried products should be considered for any procedures employed for drying. Apart from that, most of the review on literature regarding comprehensive study of drying agricultural materials often relates by either investigating the products behavior during drying or exploring different drying technologies. Consequently, various researches on thin layer drying of fruits (Doymaz, 2004a, 2004b; Simal *et al.*, 2005), vegetables (Doymaz, 2004c), grains (Cao *et al.*, 2004), leaves and grasses (Demir *et al.*, 2004; Mujaffar & John, 2018) have been reported. In spite of that, locally Shatkora is preserved by the sun drying, which is time consuming and product quality may be low. Nevertheless, it can be claimed that no literature has been studied on the thin layer drying of Shatkora in a convectional dryer. Therefore, in this experiment Shatkora was dried in a tray dryer and this paper further described the characteristics of Shatkora resulted from drying. The current work targeted to further explore the effect of temperature, air velocity and layer thickness of Shatkora peels as well as the variation with time. Moreover, the underlying quality of Shatkora by drying will be checked by measuring vitamin C content.

## 2.0 MATERIALS AND METHODS

### 2.1 Equipment

A thin layered dryer (model UOP 8, ARMPFIELD LIMITED, ENGLAND) was used to conduct the experiment and the schematic diagram are shown in Figure 1.



**Figure 1:** Schematic diagram of tray dryer

Firstly, air is drawn into the duct and passes through a mesh guard and the speed is controlled by axial flow fan impeller to generate velocities up to 1.5 m/s. Additionally, in order to control the air flow over an electrically heated element, a power regulator is used to vary the temperature up to 80°C. After that, the air flows into the center of the duct where samples to be dried are placed on the trays. Subsequently, a support frame is used to carry the trays where it is connected to a digital balance and the weight of sample is detected consistently.

A side door that is locked with a glass panel is used as a pathway to keep or remove the trays and also to monitor the conditions of the samples. After across the trays, an outlet duct section is used to discharge the air to the atmosphere, where a vane anemometer, evaluating air velocity is located. An aspirated psychrometer in which the power is supplied by a socket outlet attached on the control panel is used to determine both the wet and dry temperatures. The psychrometer are pertains to both up and down streams of the drying trays and are covered by flaps when not in use.

The equipment has an overall dimension of (1.40×2.95×0.73 m). The heating unit is constructed with an inner chamber (25× 25 × 25 cm) using a steel sheet and enclosed with an outer chamber (35 × 35 × 35 cm) by a soft board. The fiberglass insulating materials was employed to fill the gap between the two chambers. Finally, the air passes through plenum chamber (37 × 37 × 25 cm) after leaving the heating chamber for mixing and to obtain constant temperature and enter the drying chamber.

## 2.2 Evaluation of vitamin C content

The amount of Vitamin C present in Shatkora for both prior to and after drying was calculated using a standard method provided by (Majidi *et al.*, 2016).

### 2.2.1 Preparation of samples

Ten grams of Shatkora peels was blended with a laboratory blender (CHRISTISON) and was homogenized with 85 mL of 10 mM  $\text{KH}_2\text{PO}_4$  (E Merck India Limited) solution (pH=1.4). A mechanical shaker was used to agitate the solution for about 15 min. Next, the solution was poured into a 100 mL volumetric flask and again stirred gradually until a homogenous dispersion obtained. Thereafter, dilution of the sample was carried out up to the mark with 10 mM  $\text{KH}_2\text{PO}_4$  solution. Subsequently, the solution was filtered and the clear supernatant was taken to determine vitamin C content in the Shatkora.

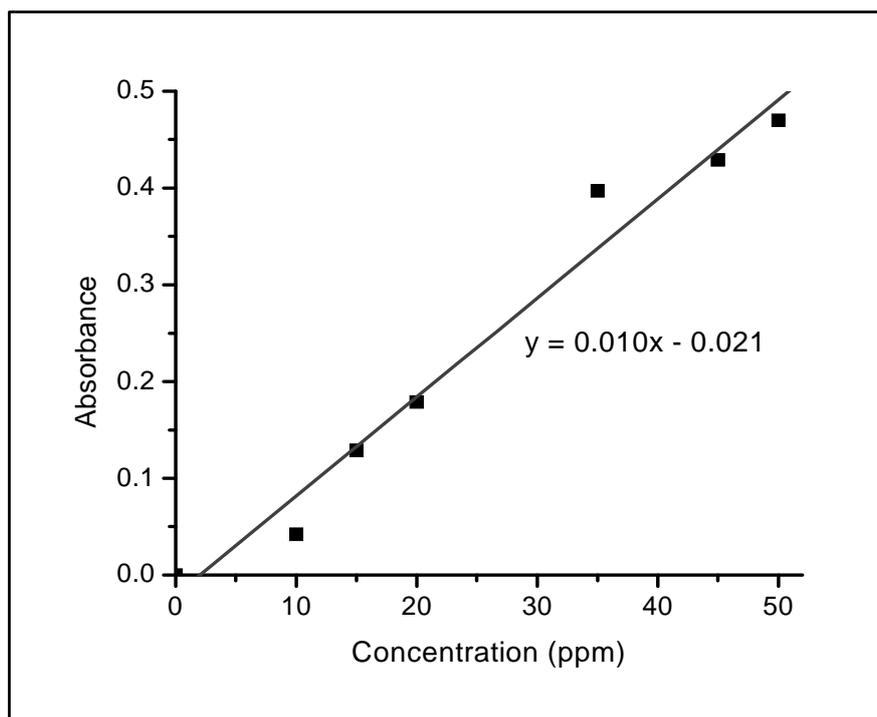
### 2.2.2 Preparation of standards

About 3 to 4 drops of bromine water were added to 4 mL of ascorbic acid (Sigma chemical co., Germany) at various concentrations (10–50 ppm) to validate the completion of ascorbic acid oxidation to dehydroascorbic acid. Next, the presence of excess bromine was eliminated by adding 1 to 2 drops of thiourea solution (10%) until the solution turns clear. In all the standards, 1 mL of 2, 4-DNPH was mixed thoroughly.

Finally, in order to complete the reactions, both the standards and the samples were kept in water bath (thermostat) at 37°C for 3 h. Once incubation was done, ice bath was used to cool the solutions and the solutions were mixed with 5 mL of 85%  $\text{H}_2\text{SO}_4$  under constant stirring until a colored solution was obtained. For obtaining a calibration curve the absorbance of the standards were plotted against their corresponding concentrations.

### 2.2.3 Estimation of vitamin C by UV method

Ascorbic acid of different concentrations were taken as a source of vitamin C and the absorbance was evaluated at 520 nm by UV-visible spectrophotometer (SHIMASZU, UV-1601). Figure 2 shows the calibration curve in which was prepared by plotting absorbance versus concentration of ascorbic acid. Additionally, this curve was being as a reference to measure the vitamin C content of the sample for both before and after drying.



**Figure 2:** Calibration curve for Vitamin C content

### 2.3 Dying experiments

Fresh Shatkora was collected from local area and stored at 4°C before the experiments. Hereby, only the peels of Shatkora were utilized in this research. The Shatkora were prepared by cutting them into smaller pieces and the fruits were removed from the peel. Prior to drying, the empty dryer was initially set to a fixed temperature and wait for at least 30 min to attain steady state before placing the Shatkora peels into the dryer. The sample mass was examined using a digital balance and afterwards placing into the dryer. Subsequently, the mass of the sample was recorded for every 10 min of time intervals. In the course of drying, Shatkora were exposed for drying until the moisture content reaches recommended method for forage materials. One-factor-at-a-time (OFAT) approach was employed to screen the reaction conditions and the experimental ranges were chosen based on the previous studies (Nicoletti *et al.*, 2001; Rajkumar *et al.*, 2007; Kaya & Aydın, 2009; Ben *et al.*, 2014). Various temperatures at the range of (40–60°C) were tested and the best temperature was selected as a constant for the second parameter. Next, the Shatkora peels were widely spread on a tray to an estimated depth ranging from (2–10 mm). Finally, the air velocity was varied from (0.50–0.90 m/s) at an optimum temperature and thickness.

### 2.4 Theory

The moisture content of Shatkora with respective to time was determined from the dry weight basis and was calculated by using equation (1);

$$X = \frac{W - W_S}{W_S} (1)$$

where,  $W$  and  $W_s$  is the weight of the sample at time  $t$  and mass of the bone dry solid respectively.

Generally, a simplified method was used to predict the diffusion coefficient (Zogzas *et al.*, 1994). For a thin plate, Baroni and Hubinger (1998) provided equation for Fick's law of diffusion, with assumptions that the transferring of moisture is only occur by diffusion, negligible shrinking, constant diffusion coefficients and temperature as well asprolonged time of drying, are given in equation (2);

$$\frac{X-X_e}{X_o-X_e} = \sum_{n=0}^{\infty} \frac{8}{(2n+1)^2\pi^2} \exp\left(\frac{-D_{eff}(2n+1)^2\pi^2 t}{4\ell^2}\right) \quad (2)$$

where,  $\ell$  is the total slab thickness if drying only from top region,  $D_{eff}$  is the effective diffusivity and  $\frac{X-X_e}{X_o-X_e}$  is the dimensionless moisture ratio.

As compared to  $X$  or  $X_o$ , the value of equilibrium moisture content is relatively small (low air relative humidity). Thus  $\frac{X-X_e}{X_o-X_e}$  can be simplified to  $X'' = \frac{X}{X_o}$  and equation (2) is modified to equation (3);

$$X'' = a \exp^{-kt} \quad (3)$$

where,  $k = \frac{-D_{eff} \pi^2}{4\ell^2}$ , and  $a = \frac{8}{\pi^2}$

$$\ln X'' = -kt + 0.21 \quad (4)$$

where,  $k = \left(\frac{D_{eff}\pi^2}{4\ell^2}\right)$  is represented by the slope of plot  $\ln X''$  vs.  $t$

Equation (5) demonstrated the Arrhenius equation which can be used to evaluate the activation energy of the material.

$$\ln D_{eff} = C - \frac{\Delta E}{RT_{abs}} \quad (5)$$

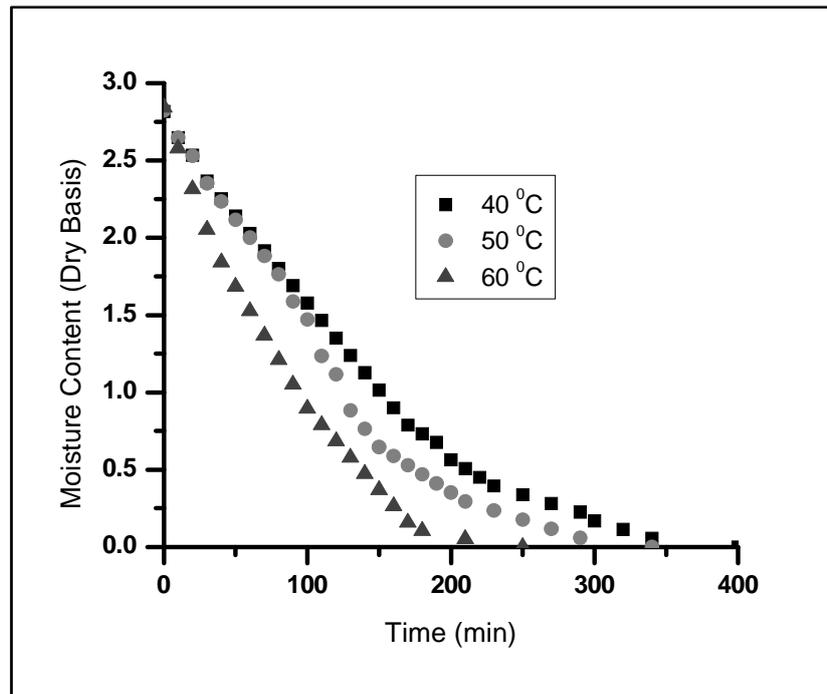
where,  $R$  is the rate constant ( $R= 8.314$  J/mol).

### 3.0 RESULTS AND DISCUSSION

#### 3.1 Effect of Shatkora on drying kinetics

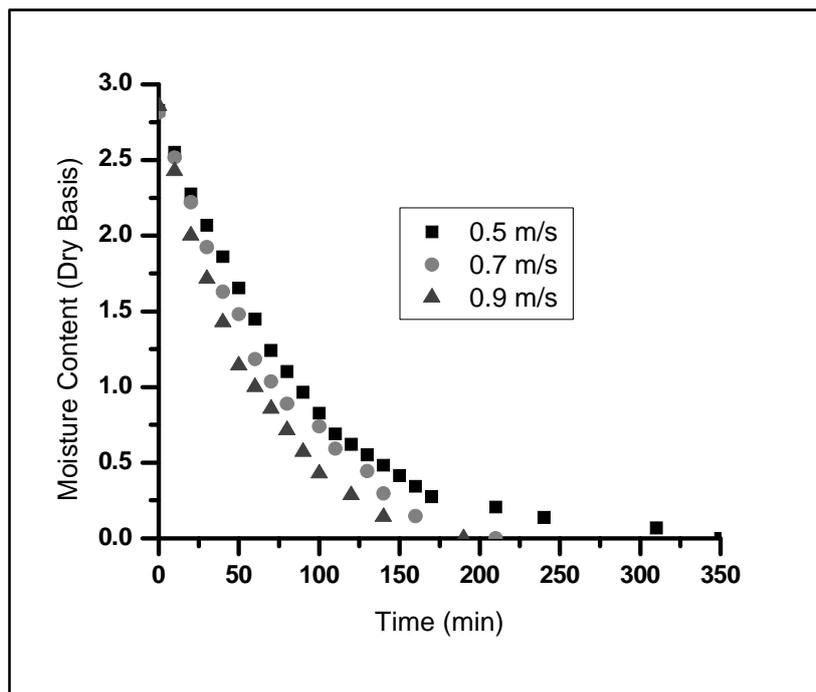
Moisture content at different time with respect to various parameters including air temperature, air velocity and thickness of the materials are shown in Figure 3, Figure 4 and Figure 5 respectively. The trend of the graph displays that decline of moisture content with time was in the form of non-linear style, demonstrating that the migration of moisture is restrained by diffusion and further subjected to the moisture in the

Shatkora peels. Moreover, the drying rate was increased with increasing temperature. The difference in moisture content with time for Shatkora layer within the temperature range of 40–60°C and thickness of 6 mm are shown Figure 3. It was noticed that the time for dried out the samples were decreased drastically by increasing the drying air temperature and this outcome supported the characteristics of most high moisture vegetables. At air temperature 40°C, the moisture contents can only be reduced up to 2.0 (decimal dry basis) or lesser however at 60°C, the reduction in moisture content was doubled and similar result was reported by (Gikuru & Joseph, 2005).



**Figure 3:** Variation of moisture content respect to drying air temperature

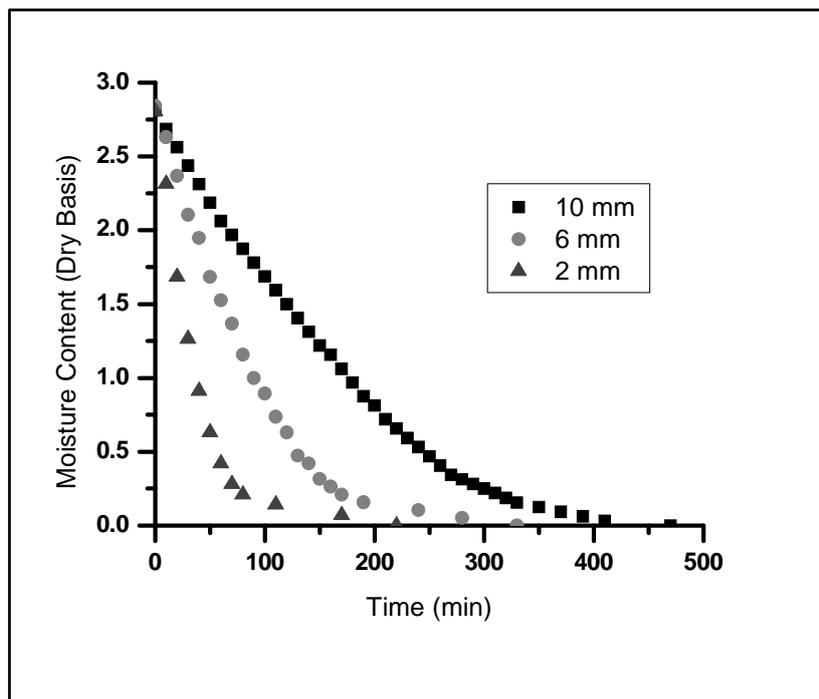
The rate of drying was also influenced by air velocity. The variation in moisture content versus time when drying Shatkora layer with a thickness of 2 mm and within the velocity ranges 0.5 to 0.9 m/s at constant temperature is shown in Figure 4.



**Figure 4:** Variation of moisture content with time and drying air velocity

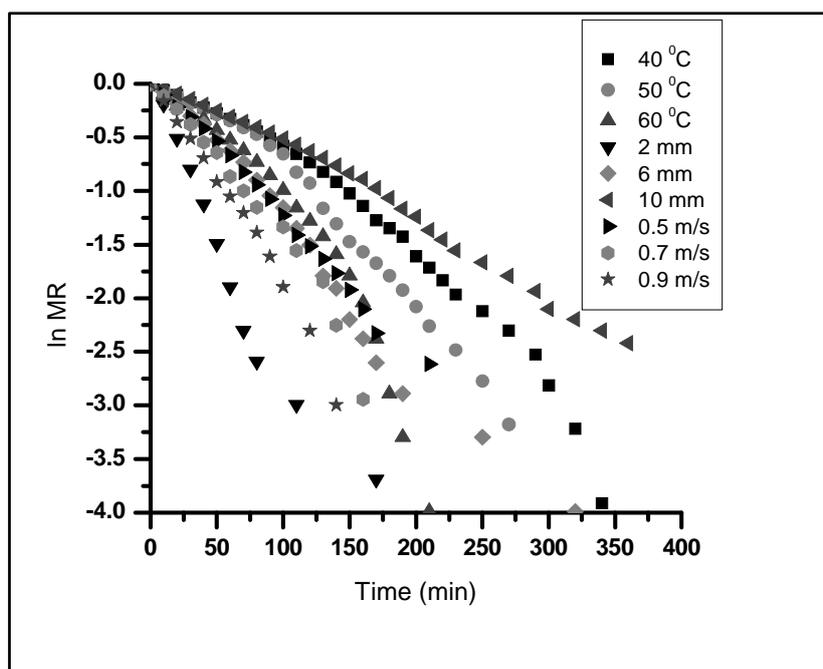
From Figure 4, it was observed that increase in air velocity causes the drying time to be rapidly decreased while increasing the removal of free moisture. At air velocity of 0.5 m/s, the time required to remove the moisture content was doubled as compared to the drying time required at air velocity of 0.9 m/s. Thus, it can be concluded that when the air flow velocity increase, the time required to reach certain moisture content was shortened and this result supported the outcome found by (Hayaloglu *et al.*, 2007).

Besides, when the thickness of the Shatkora layer was magnified, a comparative trend in the relationship between time of drying and temperature was noticed and are presented in Figure 5. At thickness 10 mm, the drying time required to remove the moisture content was approximately twice as compared to thickness of 2 mm and a similar trend was reported by (Mwithiga & Olwal, 2005). Therefore, this is an evident that increasing thickness increases the drying time whereas decreases the removal of free moisture.

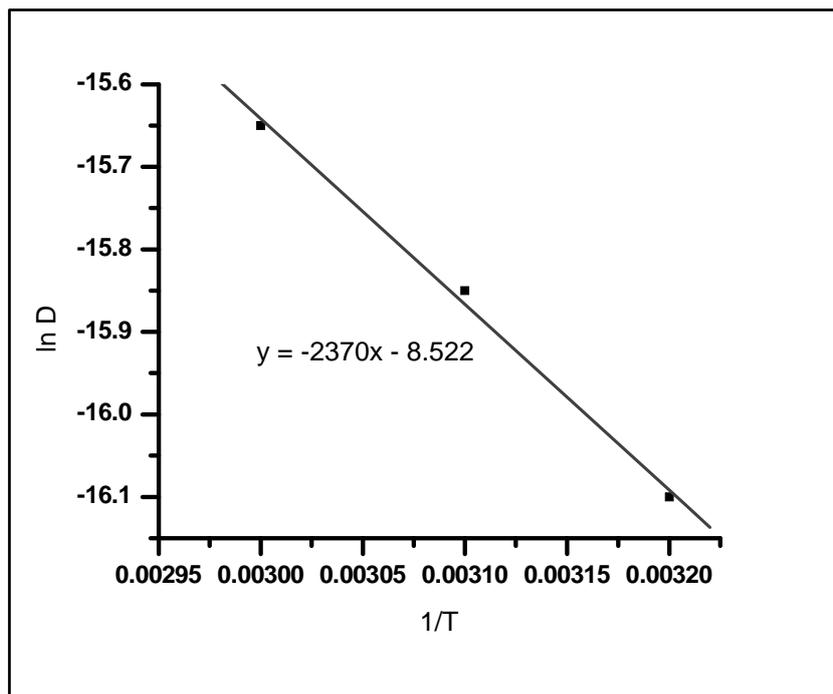


**Figure 5:** Variation of moisture content respect to drying thickness

The effective diffusivity,  $D_{eff}$  and rate constant,  $k$  was determined by plotting  $\ln X''$  vs  $t$  for various temperature, velocity and thickness and are shown in Figure 6. On the other hand, the diffusivity constant was referred to an Arrhenius type relationship and is depicted in Figure 7. The activation energy of Shatkora was also determined by using Figure 7 and equation (4) and found to be 19.70 kJ/mol, within the range of 12.87–58.15 kJ/mol (Senadeera *et al.*, 2003).



**Figure 6:** Logarithm of moisture ratio versus time for determining  $k$  value



**Figure 7:** Logarithm of thermal diffusivity versus inverse of absolute temperature

The values of rate constant ( $k$ ), effective diffusivity ( $D_{\text{eff}}$ ) and activation energy ( $\Delta E$ ) are summarized in Table 1.

**Table 1:** Drying rate constant, effective diffusivity and activation energy for Shatkora at different drying conditions

Parameters	Conditions	$k$ ( $\text{min}^{-1}$ )	$D_{\text{eff}}$ ( $\text{m}^2/\text{s}$ )	Activation energy, $\Delta E$ (kJ/mol)
Temperature ( $^{\circ}\text{C}$ )	40	0.005	$1.02 \times 10^{-7}$	19.70
	50	0.006	$1.31 \times 10^{-7}$	
	60	0.008	$1.60 \times 10^{-7}$	
Velocity (m/s)	0.5	0.005	$1.78 \times 10^{-8}$	
	0.7	0.011	$2.10 \times 10^{-8}$	
	0.9	0.029	$2.75 \times 10^{-8}$	
Thickness (mm)	2	0.012	$4.38 \times 10^{-8}$	
	6	0.014	$1.89 \times 10^{-7}$	
	10	0.017	$2.83 \times 10^{-7}$	

### 3.2 Quality changes by drying Shatkora peels

The quality (ascorbic acid) loss of Shatkora before and after drying at  $60^{\circ}\text{C}$  was also observed. It was found that after drying the Shatkora at  $60^{\circ}\text{C}$ , loss of the amount of ascorbic acid was not significant. Therefore, it can be concluded that, Shatkora can be preserved by drying at  $60^{\circ}\text{C}$ . Table 2 shows the amount of Vitamin C presents in both fresh and dried Shatkora fruits.

**Table 2:** Vitamin C content in fresh and dried Shatkora

Sample	No. of observation	Absorbance	Concentration (ppm)	Mean concentration (ppm)	Standard deviation	Total Vitamin C (mg/100 g)
Fresh Shatkora (dry basis)	1	0.767	76.7	76.26	0.368	76.26 ± 0.368
	2	0.763	76.3			
	3	0.758	75.8			
Dried Shatkora (dry basis)	1	0.7193	71.93	72.28	0.462	72.28 ± 0.462

#### 4.0 CONCLUSIONS

In this work, sliced Shatkora peels was successfully dried in a tray dryer with a thickness ranging from (2–10 mm), air temperatures (40–60°C) and air velocities (0.5–0.9 m/s). The drying rate was decreased by increasing thickness of the sample. At a given air velocity and thickness, the temperature has a remarkable impact on the drying kinetics of Shatkora. Moreover, when the drying temperature was increased from 40°C to 60°C, reduction in drying time was observed. The result also revealed that at constant temperature, the drying rate was increased with an increase of air velocity. Moreover, the drying rate constant and moisture diffusivity of sample were also increased at both high temperature and air velocity. In this study, effective diffusivity of Shatkora was determined by using Fick's second law and the moisture diffusivity was varied from  $1.78 \times 10^{-8}$  to  $2.83 \times 10^{-7}$ . Activation energy of Shatkora was also determined by the Arrhenius type relation and 19.70 kJ/mol was obtained. In contrary, research in the future should take into considerations towards the ways to enhance heated tray dryer based on loading density, fuel and electrical energy requirements.

#### ACKNOWLEDGEMENT

The authors are thankful to Shahjalal University of Science and Technology, Bangladesh and Universiti Malaysia Pahang for providing research grant (RDU180355).

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