# Investigation Effective Moisture Diffusivity and Activation Energy on Convective Hot Air Drying Assisted Extraction of Dragon Fruit Slices

**Mali Sarobol*, Preedok Sarobol, Suminya Teeta and Wanida Pharanat**

Rajabhat Maha Sarakham University, Thailand

*Corresponding author. Tel.: +66 854502702; E-mail address:

sanawong_14@hotmail.com

**Abstract**. Good drying system is evaluated by its efficiency in removing the moisture content of products to a certain level and at the same time decrease the quality degradation that occurs in drying process. The objective of this study was to investigation effective moisture diffusivity and activation energy on convective hot air drying assisted extraction of dragon fruit slices. Drying experiments were performed under 3 temperatures of 60, 70 and 80ºC, air velocities of 1.0 m/s and two thickness of thin layer of 3 and 5 mm. Investigate the effect of drying conditions on drying kinetics and qualities attributes of dragon fruit slices, namely, antioxidant activity determined by DPPH methods and total color changes ($\Delta$E) of dried dragon fruit slices. The results show that the drying time decreased with increased in drying temperature but increased with the decreasing of thin layer thickness. The highest effective moisture diffusivity thickness thin layer of 3 mm was found to be $3.55\times10^{-9}$ $m^2/s$ and thickness thin layer of 5 mm was found to be $9.21\times10^{-10}$ $m^2/s$, effective moisture diffusivity increased with the temperature. An Arrhenius relation with an activation energy showed that a higher value of thickness of thin layer of 3 mm. The experimental results showed that higher drying temperature led to higher effective diffusion coefficient, antioxidant activity and total color changes.

## 1. Introduction

Dragon fruit *(Hylocereus polyrhizus)* is a beautiful and exotic super food as it is rich in nutrients and low in calories, an excellent source of dietary fibers, vitamins, and minerals. Dehydrated dragon fruits have become more popular due to the fast preparation of dishes by people living modern lifestyles, travelling or simply appreciating convenience. This is a truly delicious and healthy snack for you during office hours or when relaxing. However, one existing problem of dehydrated fruits is the inferior rehydrated texture compared to that of freshly. Drying is an important process to extend the shelf life of dehydrated fruits before consumption. Texture and physical appearance of fruits dried may vary, depending on the method. Nowadays, many studies have reported relationships between physicochemical properties and texture of fruits dried including pineapple rings dried under combined far infrared radiation and air convection drying [1], whole longans [2], murta berries [3]. Hot air drying is the most common method used for food dehydration. It is one of the simplest drying methods with low investment and operating costs. The effective moisture diffusivity of a foodstuff characterizes its intrinsic mass transport properties of moisture including molecular diffusion, liquid diffusion, vapor diffusion, hydrodynamic flow [4]. Effective moisture diffusivity is an important physical transport property used in the engineering analysis of basic foodstuffs, i.e. apples [5].The objective of this study was to investigation effective moisture diffusivity and activation energy on convective hot air drying assisted extraction of dragon fruit slices. The effective moisture diffusivities were changes with moisture content are a consequence of different mechanisms of moisture movement during drying.

## 2. Materials and Methods

Dragon fruit or pitaya (*Hylocereus undatus*) is a climbing plant of the cactus family was purchased from the Loei Filed Crop Research Center in Loei province, Thailand as shown in **Figure 1**. Drying experiments were performed under 3 temperatures of 60, 70 and 80ºC, air velocities of 1.0 m/s and two thickness of thin layer of 3 and 5 mm. Investigated the effect of drying conditions on drying kinetics and qualities attributes of dragon fruit slices, namely, antioxidant activity determined by DPPH methods and total color changes ($\Delta$E) of dried dragon fruit slices.

**Figure 1.** Dragon fruit (*Hylocereus undatus*) [6]

For each experiment, 1,000 g of freshly dragon fruit was spread on a stainless steel wire mesh tray and the sample tray was placed in the drying chamber. The thickness of thin layer dragon fruit slices at 3 and 5 mm. Moisture contents of the samples were determined using the air oven method of AACC[7]. The moisture content was determined by drying triplicate. The color of samples was determined by a Hunter Lab colorimeter (MiniScan XE Plus, Henter Associates Laboratory, Inc., USA). Antioxidant activities was determined by DPPH methods, which was described by Benzie and Strain. [8]

***2.1 Effective moisture diffusivity*** : To determine effective moisture diffusivity, Dragon fruit slices were assumed to be slab. An analytical solution of Fick's second law for a spherical shape can be expressed by Eq. (1) [4]

$$MR = \frac{8}{\pi^2} \sum_{n=0}^{n=\infty} \frac{1}{(2n+1)^2} \exp\left( -D_{eff} \frac{(2n+1)^2 t}{4L^2} \right) \tag{1}$$

where L is half thickness of the slab, n is the positive integer, and $D_{eff}$ is effective diffusivity coefficient.

Only the first term of Equation (1) is used for long drying periods, only the first term of the equation is often applied as used by various researches as follows from: Eq. (2)

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

The energy of activation was calculated by using an Arrhenius type equation (3)

$$D = D_0 \exp\left(-\frac{E_a}{RT_a}\right) \quad (3)$$

Where Ea is the energy of activation (kJ/mol), R is universal gas constant (8.3143 kJ/mol), $T_a$ is absolute air temperature (K), and $D_0$ is the pre-exponential factor of the Arrhenius equation ($m^2/s$).

***2.2 Determination of color :*** The color indices represent light to dark ($0 \leq L \leq 100$), green to red ($-60 \leq a \leq 60$), and blue to yellow ($-60 \leq b \leq 60$). Total color difference (*ΔE*) is another important color index. It can be calculated using the following equation (4).

$$\Delta E = \sqrt{(\Delta L)^2 + (\Delta a)^2 + (\Delta b)^2}$$

$$\Delta L = L - L_0,\ \ \Delta a = a - a_0,\ \ \Delta b = b - b_0 \quad (4)$$

Where *L*, *a* and *b* are lightness, redness and yellowness of the sample after drying and $L_0$, $a_0$, and $b_0$ are the values before drying. Each dried sample was measured three times from different parts of the total sample and averages were determined from 3 samples.

***Error analyses:*** Correlation coefficients ($R^2$) and root mean square error (RMSE) were criteria for the accuracy of the fit. The higher $R^2$ and the lower RMSE represent good fits to the model. These parameters were calculated as follows:(5),(6)

$$R^2 = 1 - \frac{\sum_{i=1}^{N}\left(X_{pre,i} - X_{exp,i}\right)^2}{\sum_{i=1}^{N}\left(X_{pre,ave} - X_{pre,i}\right)^2} \quad (5)$$

$$RMSE = \sqrt{\frac{1}{N}\sum_{i=1}^{N}\left(X_{pre,i} - X_{exp,i}\right)^2} \quad (6)$$

where $X_{exp,i}$ is the $i^{th}$ experimental values, $X_{pre,i}$ is the $i^{th}$ predicted values, $X_{exp,ave}$ is the $i^{th}$ experimental average values, N is the number of observations and z is the number of constants.

**3. Results and discussion**

The drying curves of dehydrated dragon fruits under 3 drying temperatures at 60, 70 and 80ºC were shown in **Figure 2.** This figure showed that the moisture content of dragon fruits in all drying conditions decreased exponentially with elapsed drying time. The moisture content was a consequence of different mechanisms of moisture movement during drying. The moisture diffusivity of food material is affected by its moisture content, temperature. The values of effective moisture diffusivity for all drying conditions were presented in **Table 1**. The highest effective moisture diffusivity thickness thin layer of 3 mm was found to be $3.55\times10^{-9}$ $m^2/s$ and thickness thin layer of 5 mm was found to be $9.21\times10^{-10}$ $m^2/s$. The moisture gradient of the sample with ambient temperature increases and causes an increase in moisture diffusivity. Effective diffusion coefficient is a function of temperature and moisture content of material[4].

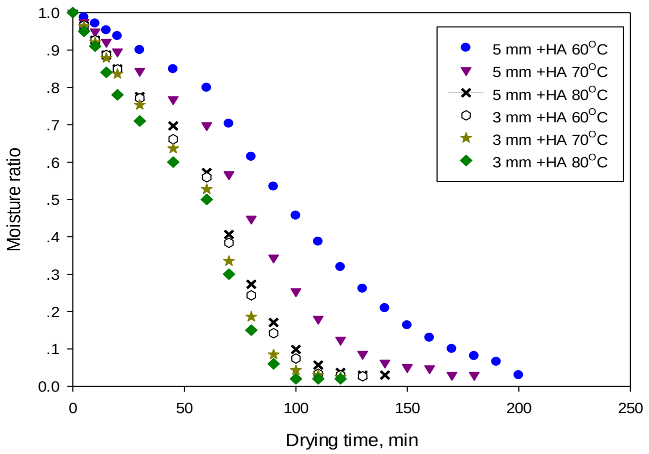


**Figure 2.** Changes of the moisture content of dragon fruits under different drying conditions

**Table 1.** Effective moisture diffusivities of dragon fruits drying undergoing different conditions

| Drying conditions | $D_{eff}$ ($m^2/s$) | $R^2$ | RMSE |
|---|---|---|---|
| 3 mm+ HA 60°C | $1.79 \times 10^{-9}$ | 0.993 | 0.030 |
| 3 mm+ HA 80°C | $3.55 \times 10^{-9}$ | 0.998 | 0.041 |
| 5 mm+ HA 60°C | $4.33 \times 10^{-10}$ | 0.965 | 0.075 |
| 5 mm+ HA 80°C | $9.21 \times 10^{-10}$ | 0.997 | 0.046 |

The activation energy is usually represented by the symbol $E_a$. The energy of activation was calculated by using an Arrhenius type equation. An Arrhenius relation with an activation energy showed that a higher value of thickness of thin layer of 3 mm. An Arrhenius relation with an activation energy value of 13.28 to 17.87 kJ/mol. Effect of different drying temperatures of dragon fruits on the DPPH radical scavenging activity is summarized in **Table 2.** The drying condition at 5 mm+ HA 60°C led to higher antioxidant activity changes. The radical scavenging activity for dragon fruits dried reached up to 15.47 µM Trolox/g dry sample. However, nutrients and antioxidant components of foodstuff may be change with processing, especially higher drying temperature.

**Table 2.** The antioxidant activity changes of dragon fruits drying undergoing different conditions

| Drying conditions | Moisture content (% d.b.) | DPPH (µM Trolox/g dry sample) |
|---|---|---|
| 3 mm+ HA 60°C | 9.03 ± 0.01 | 14.38 ± 0.22 |
| 3 mm+ HA 80°C | 8.26 ± 0.01 | 11.85 ± 0.39 |
| 5 mm+ HA 60°C | 10.02 ± 0.04 | 15.47 ± 0.55 |
| 5 mm+ HA 80°C | 9.12 ± 0.01 | 11.93 ± 0.32 |

The total color difference value increased with increasing drying temperature. Experiments were performed at hot air drying conditions of 3 mm+ HA 60$^{O}$C the total color difference ($\Delta E$) was 8.68, conditions of 3 mm+ HA 80$^{O}$C was 18.27. Color changes can be attributed to the occurrence of Maillard reaction between carbonyl groups of reducing sugars and amino groups of amino acids, peptides, or proteins [9].

## 4. Conclusions

The effective moisture diffusivity and antioxidant activity in all drying conditions was increased with the increase of the drying air temperature. The radical scavenging activity for dragon fruits dried reached up to 15.47 µM Trolox/g dry sample. Effective diffusion coefficient is a function of temperature and moisture content of material. The highest effective moisture diffusivity thickness thin layer of 3 mm was found to be $3.55\times10^{-9}$ $m^2$/s and thickness thin layer of 5 mm was $9.21\times10^{-10}$ $m^2$/s. An Arrhenius relation with an activation energy showed that a higher value of thickness of thin layer of 3 mm was found to be 13.28 to 17.87 kJ/mol.

## 5. Acknowledgements

The authors would like to gratefully acknowledge the Research and development institute Rajabhat Maha Sarakham Universitying (RMU, Thailand) for the financial support.

## References

[1] Ponkham, K., Meeso, N., Soponronnarit,S., Siriamornpun, S.(2012). Modeling of combined far-infrared radiation and air drying of a ring shaped-pineapple with/without shrinkage. *Food Bioprod. Process.* V.**90(2)**, 155-164.

[2] Nuthong, P., Achariyaviriya, A., Namsanguan, K., Achariyaviriya, S.,(2011).Kinetics and modeling of whole longan with combined infrared and hot air. *J. Food Eng.* **V.102(3)**, 233-239.

[3] Puent-Diaz, L., Ah-Hen, K., Vega-Galvez, A., Lemus-Mondaca, R., Scala, K., 2013. Combined Infrared-Convective Drying of Murta (Ugni molinae Turcz) Berries: Kinetic Modeling and Quality Assessment. *Drying Technol.* V.**31(3)**: 329-338.

[4] Karathanos, V. T., Villalobos, G. and Saravacos, G. D.,. (1990). Comparison of two methods of estimation of the effective moisture diffusivity from drying data. *J.Food Sci.* **V.55(1)**: 218-223.

[5] Feng, H., Tong, J., Cavalieri, R.P., (1999). Combined microwave and spouted bed drying of diced apples: effect of drying conditions on drying kinetic and product temperature. *Drying Technol.* **V.17(10)**: 1981-1998.

[6] Dragon fruit. Retrived from http://www.pharmacy.mahidol.ac.th

[7] AACC., (2008). Approved Methods of the American Association of Cereal Chemists, 10th ed. St. Paul, MN.

[8] Benzie, I and Strain, J. (1996). The Ferric Reducing Ability of Plasma (FRAP) as a measure of antioxidant power: The FRAP assay, *J.of Analytical Biochem*, **V.39**, pp. 70-76.

[9] Oh, S., Lee, Y., Lee, J., Kim, M., Yook, H., Byun, M., 2005.The effect of γ-irradiation on the non-enzymatic browning reaction in the aqueous model solutions. *Food Chem.* **V.92(2)**: 357-363.