

The Drying Kinetics of Chilies using a Rotating Fluidized Bed Technique

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Abstract: Problem statements: The present study investigates experimentally the drying of chilies (*Capsicum annuum* L.) with rotating fluidized bed technique and the biological properties: capsaicin content, moisture diffusivity and activation energy. **Approach:** The drying experiment was conducted at the drying air temperatures ranged 70-120°C and the drying air velocity was fixed at 1.8 m sec⁻¹, while the layer's height was fixed at 4 ± 0.5 cm. The chilies were dried starting 350 ± 5%db down to 10 ± 1%db. **Results:** The drying time requested to dry chilies ranged 69-257 min. The average capsaicin content of dried chilies was decreased starting 2725.4 down to 1617.4 ppm. The effective diffusivity and activation energy were also described. **Conclusion:** Drying air temperature was significant factor on the decreasing of moisture content, capsaicin content and redness of dried chilies. All samples can be marketable.

Key words: Rotating Fluidized Bed (RFB), drying kinetics, dried chilies, moisture diffusivity, drying air temperature, *Capsicum annuum* L., centrifugal fluidized, sunlit drying, linear logarithmic, cylindrical food

INTRODUCTION

The chilies are commonly used as condiment and they are the ripe fruits of the species of genus capsicum (Amaroek *et al.*, 2010). After harvest, chilies contained high moisture estimated 400%db (Amaroek *et al.*, 2010); nevertheless, moisture content of 16%db were acceptable in the export market (Amaroek *et al.*, 2010). Then, chilies must be dried for making chili powder and for keeping in the short or long term storages.

A Rotating Fluidized Bed (RFB) which one of among of fluidized bed techniques is an air-distributor that can be rotated about its axis of symmetry with airflow introduced in the inward direction of the radius to fluidize the bed. Instead of having a fixed gravity field as in a conventional fluidized bed, the body force in a centrifugal bed becomes an adjustable parameter that is determined by the rotating speed and air-distributor radius. By using the strong centrifugal field much greater than gravity, the particle bed is able to withstand a large amount of airflow without serious formation of large bubbles and the gas-solid contact at high airflow is improved (Abdullah *et al.*, 2010). The drying kinetics food from RFB were found only a few samples in published literature, e.g., soybean, green

bean and rice (Chen *et al.*, 1999 and Elmi *et al.*, 2009) that almost sphere.

On the other hand, the cylindrical food, such as, chilies are scanty; in addition, the capsaicin of dried chilies based on drying temperature are scanty, too.

For the objectives of this study are (i) to investigate experimentally the drying kinetics of chilies in RFB technique, (ii) and to investigate the capsaicin content in dried chilies, moisture diffusivities and activation energies.

MATERIALS AND METHODS

Sample: The chilies (*Capsicum annuum* L.) which are freshly obtained from the market (average length of 65 ± 5 mm and average diameter of 7.8 ± 2 mm) are used in this study. The initial moisture contents was measured by AOAC (2000) 930.04 method (Stephen and Emmanuel, 2009; Ibrahim *et al.*, 2009) where the Central Laboratory (Thailand) Co., Ltd., Khon Kaen Branch, Thailand, that certificated from the laboratory accreditation with ISO/IEC 17025.

Experimental apparatus: The Rotating Fluidized Bed (RFB) technique or so-called a centrifugal fluidized bed technique can be used to dry several grains. The grains

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are introduced inside an air-distributor and are forced to the wall by a centrifugal force due to the rotation of the air-distributor. The air flows radially inward through the air-distributor and the forces on the grain (Fig. 1) are balanced by the airflow (drag force and buoyancy force) and the centrifugal force (Watanoa *et al.*, 2003; Elmi *et al.*, 2009; Opafunso *et al.*, 2009). The variable defined r is radius of an air-distributor (m) and ω is an angular velocity (rad sec^{-1}). The air-distributor always rotates in the clockwise direction in this study.

For RFB apparatus can be seen at Fig. 2, it is a schematic diagram of the experimental apparatus for this study. The air-distributor with 400 mm diameter and 200 mm width can be rotated around a horizontal axis. The rotating speed can be adjustable for the several drying conditions. Additionally, the dimension of side surface of air-distributor are 2.5 mm in hole and 38.5% in open area. The rotating speed can be adjusted by a frequency inverter and measured by RPM-meter (Tachometer Digital Meter, DTO6234N and Germany) with an accuracy of $\pm 0.1\%$. For visualizing, the transparent glass was installed at the end wall. The high-speed video camera was observed the fluidization behaviors. For exhaust air, a filter of 100 mm diameter was located at the center of the air-distributor. The drying air was blown by a blower of 5 HP which was adjusted the rotating speeds by frequency inverter. The drying airflow was measured by an orifice meter with U-shaped manometer. The pressure drop through the bed was measured by a U-shaped manometer. An electric heater, the drying air was heated by an electric heater of 5 kW and adjusted by PID control (Suntree, SG6, USA) with an accuracy of $\pm 0.1\%$. For temperature, J-type iron-constantan thermocouple was used: thermometer indicators (NS, YB05C-A1 and China) with an accuracy of $\pm 0.05\%$. An apparatus was constructed for the experiment in this study it was installed at the Khon Kaen University, Thailand.

Drying method: For drying with RFB, the procedures were defined as following. First of all, an electric heater was started upon drying conditions with the six intervals of the drying air temperatures; namely, 70, 80, 90, 100, 110 and 120°C at the drying air velocity of 1.8 m sec^{-1} .

An experimental apparatus was operated with the operation time of 60 min for stabilizing the drying condition. The second, the 2 kg samples (estimated $4 \pm 0.5 \text{ cm}$ of the bed layer height) were filled into the air-distributor (drying chamber) they are an initial weight of the sample. The third, the air-distributor was started with the rotating speed of $106 \pm 0.1 \text{ rpm}$.

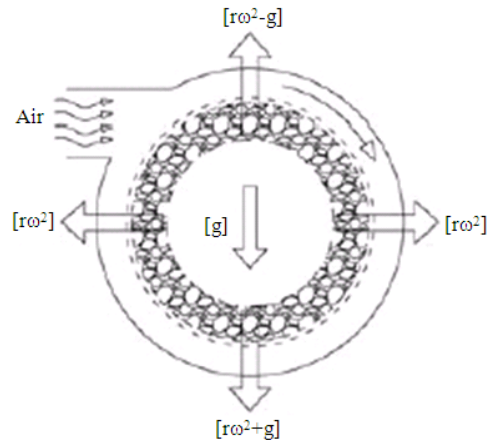


Fig. 1: The several forces in RFB technique

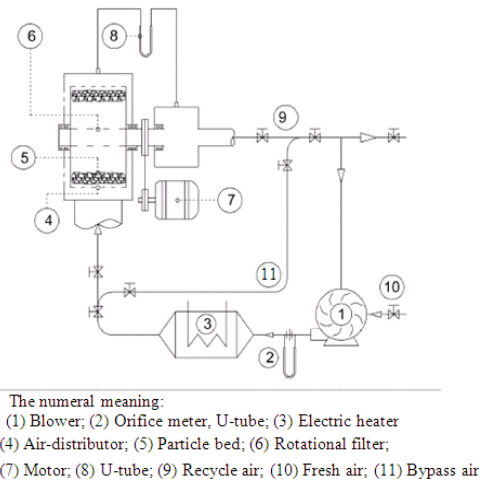


Fig. 2: Diagram of RFB system

Finally, the moisture loss was recorded every 10 min during drying processes by a digital balance (OHAUS, PA512, USA) with an accuracy of $\pm 0.01 \text{ g}$. The samples are dried from the initial moisture content of $350 \pm 5\% \text{ db}$ down to moisture of $10\% \pm 1 \text{ d.b.}$ The experiment was repeated three times and the average data was evaluated for analysis.

For drying with sunlight, a kilogram of chilies were exposed under the sunlight. The samples were kept in a container at night. This process was conducted continuously in a span of 12-15 days.

Theoretical considerations: The moisture movement inside the particle was developed based on Fick's second law of diffusion (Quasem *et al.*, 2009; Yahya *et al.*, 2010). The chilies are assumed to the infinite length cylinder which is the equation of conservation of energy is:

$$\frac{\partial M}{\partial t}(r,t) = D_{\text{eff}} \left[\frac{\partial^2 M}{\partial r^2} + \frac{c}{r} \frac{\partial M}{\partial r} \right] \quad (1)$$

The variable, M is the moisture content at anytime in unit of decimal of dry basis (db), D_{eff} is effective moisture diffusivity of grains ($\text{m}^2 \text{sec}^{-1}$), t is drying time (s), r is radial distance from center of grains (m) and c is constant. Assuming uniform initial moisture distribution and negligible external resistance, the solution proposed by following (Amaroek *et al.*, 2010):

$$MR = \sum_{n=1}^{\infty} \frac{4}{b_n^2} \exp \left[-\frac{b_n^2 D_{\text{eff}} t}{r_c^2} \right] \quad (2)$$

The variable, r_s is radius of grain (m), M is average moisture content at anytime (dry basis) and b is root of Bessel's function of order zero. For long drying times (setting $n = 1$), an Eq. 2 can be further simplified to a straight line equation as (Sayyar *et al.*, 2009):

$$\ln(MR) = \ln \left[\frac{4}{b^2} \right] - \left[\frac{b^2 D_{\text{eff}}}{r_c^2} \right] t \quad (3)$$

To determine the effective diffusivity coefficient, D_{eff} , the slope of the relationships between $\ln(MR)$ and time (Eq. 3) is computed and then D_{eff} is calculated by the following equation:

$$\text{Slope} = \frac{b^2 D_{\text{eff}}}{r_c^2} \quad (4)$$

Moistures ratio of sample during the thin-layer drying experiment is calculated with the following equation (Brooks *et al.*, 2008; Charmonkolpradit *et al.*, 2010):

$$MR = \frac{M - M_e}{M_o - M_e} \quad (5)$$

The equilibrium moisture content, M_e , can be negligible because it is very small (Quasem *et al.*, 2009; Sghaier *et al.*, 2009) compared with M or M_o . Consequently, the Eq. 6 can be rewritten to:

$$MR = \frac{M}{M_o} \quad (6)$$

The moisture diffusivity (D_{eff}) increases with the increase in drying temperature; (Hii *et al.*, 2009; Sayyar *et al.*, 2009). The temperature effect is modeled using well know Arrhenius type relationship (Sayyar *et al.*, 2009).

$$D_{\text{eff}} = D_o \exp \left[\frac{E_a}{RT} \right] \quad (7)$$

By taking the natural logarithm of both sides, the above exponential form of Arrhenius can be transfigured into a linear Logarithmic form:

$$\ln(D_{\text{eff}}) = \ln(D_o) - \left[\frac{E_a}{R} \right] \left[\frac{1}{T} \right] \quad (8)$$

The variable, E_a is the activation energy (kJ kgmol^{-1}) and D_o is the Arrhenius's factor (Sayyar *et al.*, 2009; Sghaier *et al.*, 2009). ($\text{m}^2 \text{sec}^{-1}$) that were determined by plotting $\ln(D_{\text{eff}})$ versus $(1/T)$. The variable, R is universal gas constant ($8.314 \text{ kJ kgmol.K}^{-1}$) and T is absolute temperature (K). Analysis of variance was carried out to find the effects ($p < 0.05$) of drying air temperature.

RESULTS

Drying kinetics: The comparison to the drying kinetics of six intervals of drying air temperatures have shown the rate of moisture reduction that was greatest at a highest temperature (Fig. 3). It responded the influence of drying temperature on the ability to diffuse moisture ($p < 0.05$). It can be described after that have ventilated the gas velocity in RFB technique, the turbulence and mixing of the fluidized particles were intensified. Then, the gas film on the particles becomes thin, so the gas-solid heat transfer was improved (Kowalski *et al.*, 2010). In addition, after increased the temperature of drying air from 70-120°C, the latent heat was intensified, so the dehydration from the moist produce was improved (Bovornsethanan and Wongwises, 2007; Brooks *et al.*, 2008; Theansuwan *et al.*, 2008).

The researchers have been recently reported the same phenomenon for other grain, such as red chilies (Anwarul Huq and Arshad, 2010), Bird's chilies (Amaroek *et al.*, 2010), chopped coconut (Madhiyanon *et al.*, 2009) and apple (Marjan *et al.*, 2010). The drying time to dry chilies from initial moisture content of approximately $350 \pm 5\%$ db to final moisture content of approximately $10 \pm 1\%$ db were 257, 163, 131, 98, 78 and 69 min at 70, 80, 90, 100, 110 and 120°C of drying air temperature, respectively. It was reported that the using of another dryer took 13 h to dry chilies from 325-10.5%db at 65°C of drying air temperature (Amaroek *et al.*, 2010; Mazloomi *et al.*, 2010) and

106.7 min to dry the sliced bird's eye chilies to 16%db at 70°C of drying air temperature (Omar *et al.*, 2008). Initially, the abundance of free water on the produce surface contributed the effortless moisture liberation; however, much more difficult it might be to expel water after that, when the produce surface becomes harder due to shrinkage (Kowalski *et al.*, 2010).

DISCUSSION

Redness: The redness of dried chilies at different conditions was observed. The results shown the redness deterioration after drying both RFB technique and sunlit drying were investigated. They are differences in redness from two different methods; namely, the dried chilies from sunlit drying appear the light red; on the other hand, from a RFB appear dark redness (Fig. 4).

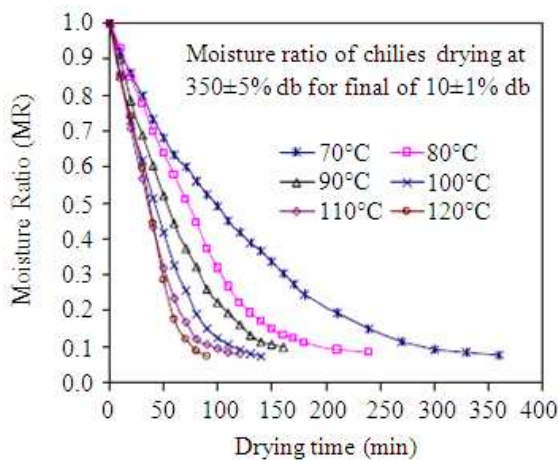


Fig. 3: Experimental drying curves relationship between moisture ratio and drying time



Fig. 4: The comparable redness of the dried chilies (*Capsicum annuum* L)

When the drying air temperature increases starting 70-120°C, the redness is also affected adversely; on the other hand, it can be marketable. It may be due to the oxidation of carotenoid pigments at the elevated temperatures. This behavior was similarly reported by Omar *et al.* (2008). The chilies dried under the sunlight for about 12-15 days can be registered the moisture content of 10 ± 1%db. This drying kinetics was similar reported by Amaroek *et al.* (2010). Nevertheless, the drying time for sunlit drying is far too long compared to drying with a RFB with only requires a few hours.

Capsaicin content: Capsaicin is the main capsaicinoid in chilies, followed by Dihydrocapsaicin. These two compounds are also about twice as potent to the taste and nerves while the minor capsaicinoids are Nordihydrocapsaicin, Homodihydro-capsaicin, Homocapsaicin and Nonivamide (Cisneros-Pineda *et al.*, 2007; Ornela-Paz *et al.*, 2010). The analysis of capsaicinoids content in this study represented to the capsaicin (8-Methyl-N-vanillyl-trans-6-nonenamide) in dried chilies (*Capsicum annuum* L.). The method to investigate the capsaicinoid content was made by HPLC based on AOAC (2005) 995.03 in house method and tested at Central Laboratory (Thailand) Co., Ltd., Khon Kaen Branch, Thailand-that certificated from the laboratory accreditation with ISO/IEC 17025. Each dried chilies was analyzed in four replications while the level of capsaicin content with the use of ppm (mg kg⁻¹) unit was also determined. The volume of the lowest significant difference was determined with p≤0.05. They were determined in among dried chilies in difference of drying air temperature and represented more than 70% of the total capsaicinoids in the dried chilies (Omar *et al.*, 2008; Pompimon *et al.*, 2009). For the first repeated sample at drying air temperature of 70°C allowed us to infer that peak at RetTime of 3.403 min and 4.341 min for capsaicin content of 2709.1 ppm and dihydrocapsaicin content of 1488.6 ppm, respectively while other detail can be seen in Fig. 5 and Fig. 6; in addition, the results of other repeated drying can be seen in Table 1. The results shown the average capsaicin contents of dried chilies decreased from 2725.4 to 1617.4 ppm as the drying air temperature increased from 70-120°C while the average capsaicin of dried chilies after sunlit drying method are 2943.8 ppm. It clearly shows that the capsaicin of chilies was affected adversely when higher temperatures were used for drying (p<0.05). Similar results were quoted in the case of red chilies drying (Amaroek *et al.*, 2010). The polynomial equation was fitted capsaicin “Cap” (ppm) versus drying air temperature “T” that can be seen at Fig. 5 as follows:

$$\text{Cap} = 0.3495T^2 - 86.924T + 7050.132 \quad (9)$$

where, R² = 0.982 and temperature(T) ranged 70-120°C.

Table 1: The capsaicin contents at different drying air temperatures in dried chilies after dried starting 350±2-10±1% db

Drying air temperature (°C)	Capsaicin contents (ppm)				
	1st repeated	2nd repeated	3rd repeated	Average	STD
70	2709.1	2712.1	2755.0	2725.4	25.7
80	2326.9	2203.4	2246.5	2259.0	62.6
90	2059.8	2007.6	2026.9	2031.5	26.4
100	1852.6	1892.7	1967.8	1904.4	58.4
110	1782.7	1750.1	1730.2	1754.3	26.4
120	1516.1	1665.1	1671	1617.4	87.7
Sunlit drying	2924.2	2963.3	-	2943.8	27.6

Note: The 1st, 2nd and 3rd are the repeated drying sample, respectively. “STD” and “Sunlight” are the standard deviation and chilies drying by sunlight, respectively

Table 2: The values of drying time and average moisture diffusivities, D_{eff} at different temperatures

Temperature (°C)	Drying time (min)	Deff (m ² sec ⁻¹)
70	257	0.42×10 ⁻⁹
80	163	0.72×10 ⁻⁹
90	131	0.89×10 ⁻⁹
100	98	1.11×10 ⁻⁹
110	78	1.51×10 ⁻⁹
120	69	1.67×10 ⁻⁹

Table 3: Moisture diffusivities and activation energy of chilies and other products

Products	Temperature (°C)	$D_{eff} \times 10^9$ (m ² sec ⁻¹)	E_a (kJ mol ⁻¹)
Chilies (Present study)	70-120	0.42-1.67	30.39
Black tea (Panchariya <i>et al.</i> , 2002)	80-120	0.01-0.03	406.02
Yong coconut (Madamba, 2003)	50-70	0.17-0.55	65.16
Parboiled wheat (Mohaprtra and Rao, 2005)	40-60	0.12-0.28	37.01
Corn (Doymaz and Pala, 2003)	55-75	0.09-0.17	29.56
Apple pomace (Wang <i>et al.</i> , 2007)	75-105	2.02-3.93	24.51

Moisture diffusivity: The Fick’s law can be adopted into the simulation (Eq. 2). The values of D_{eff} associated with temperatures of 70-120°C (Table 2) are 0.42×10-9 to 1.67×10-9 m² sec⁻¹. As expected, drying air temperature had an appreciable effect on D_{eff} , which increased vigorously with increase in temperature that can be fitted in linear equation as following.

$$D_{eff} = 1.1 \times 10^{-11} T - 6.28 \quad (10)$$

Where, $R^2 = 0.984$ and temperature (T) ranged 70-120°C. It is important to underline that the typical values of D_{eff} for food and biological materials (Table 3). Due to its effective mixing mechanism, the rotating fluidized bed can expedite heat and mass transfer between drying air and chilies.

The more rapidly heat was conveyed to the product and the greater mass transfer rate was achievable; as a result, D_{eff} was enhanced. In addition, the relatively length of the dried chilies (length of 65 ± 5 mm) may aid dehydration, because the D_{eff} dominate mass transfer and the characteristic length played crucial roles.

Characteristic length is inversely related to internal mass transfer resistance (Karim and Hawlader, 2005; Madhiyanon *et al.*, 2009), so that the longer the length of chilies to be dried, the greater moisture immigration to the chilies surface.

Activation energy: The ln-values of activation energy, analyzed by Arrhenius expression (Eq. 7) and plotted versus the reciprocal of absolute temperature (Fig. 7) has shown a linear relationship. The activation energy, E_a , gained from the line slop yielded a value of 30.39 kJ mol⁻¹ and the pre-exponential, D_o , derived from the axis intercept point is 1.99×10-5 m² sec⁻¹. As summarized in Table 3, the comparisons of E_a with other researcher for a diversity of agricultural product are suggested. The present values shown the black tea it was rather high.

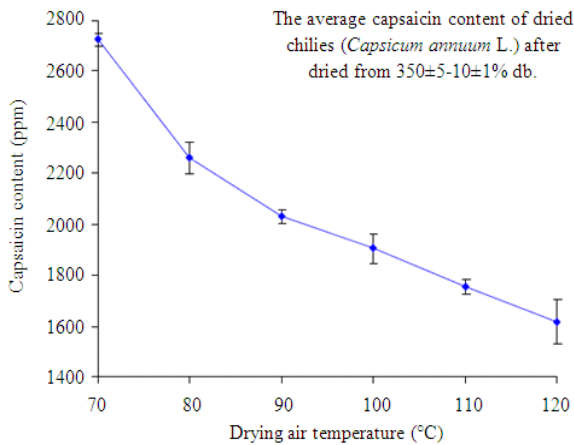


Fig. 5: Relationship between capsaicin Vs temperature

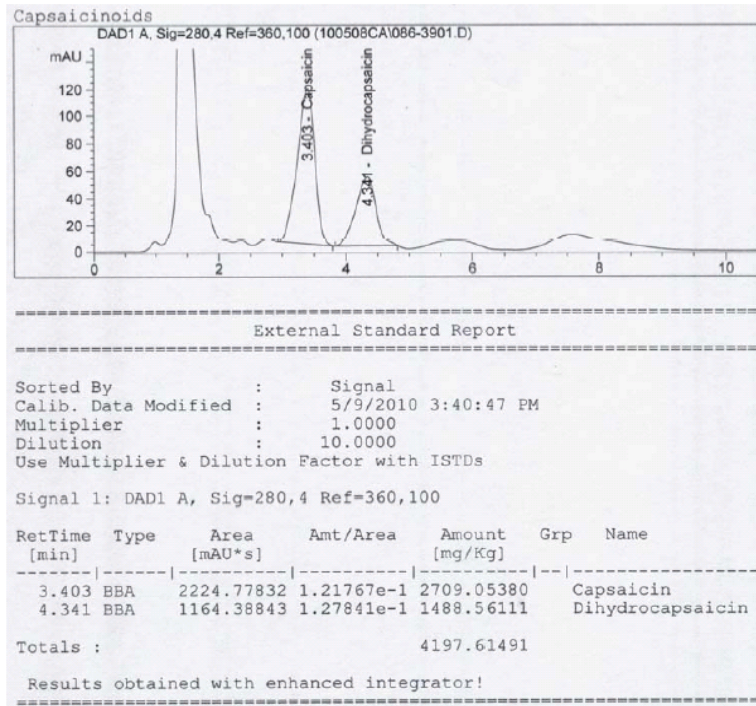


Fig. 6: Chromatogram of capsaicin and dihydrocapsaicin in dried chilies

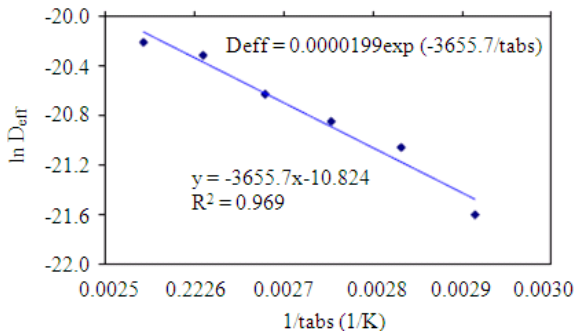


Fig. 7: Arrhenius-type relationship between moisture diffusivity and reciprocal of absolute temperature

CONCLUSION

The chilies drying on the Rotating Fluidized Bed (RFB) technique can be concluded as following. Drying kinetic, the influence of drying temperature on the ability to diffuse moisture that can be described after that have ventilated the gas velocity in RFB technique, the turbulence and mixing of the fluidized particles were intensified; in addition, after increased the temperature of drying air from 70-120°C, the latent heat was intensified, so the dehydration from the moist

produce was improved (Sghaier *et al.*, 2009; Brian Boswell *et al.*, 2009; Singh and Pandey, 2010). Redness, they are differences in redness from two different methods; namely, the dried chilies from sunlit drying appear the light red; on the other hand, from a RFB appear dark redness. It may be due to the oxidation of carotenoid pigments at the elevated temperatures (Amaroek *et al.*, 2010). Capsaicin, the average capsaicin contents of dried chilies decreased from 2725.4-1617.4 ppm as the drying air temperature increased while the average capsaicin of dried chilies after sunlit drying method are 2943.8 ppm. It clearly shows that the capsaicin of chilies was affected adversely when higher temperatures were used for drying. Similar results were quoted in the case of red chilies drying (Amaroek *et al.*, 2010). Moisture diffusivities, D_{eff} , drying air temperature had an appreciable effect on its and increased vigorously with increase in temperature. Activation energy, E_a , gained from the line slop yielded a value of 30.39 kJ mol⁻¹.

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