Equilibrium Moisture Content of Thai Red Chillies

**Sukruedee Nathakaranakule*, Wattanapong Rakwichian*,
Rak Dandamrongrak**, Sirichai Thepa*****

*School of Renewable Energy Technology, Naresuan University,
Phitsanulok 65000, Thailand
**Faculty of Agriculture Natural Resources and Environment, Naresuan University,
Phitsanulok 65000, Thailand
***School of Energy and Materials, King Mongkut's University of Technology Thonburi,
Bangmod, Thungkru, Bangkok 10140, Thailand
Tel: +66-5526-1000 ext. 3188, Fax: +66-5526-1067, E-mail: sukruedeen@nu.ac.th

ABSTRACT

The relation between air relative humidity and moisture content of the test material is necessary for drying and storage process research. The objectives of this work were to establish the experimental equilibrium relative humidity-equilibrium moisture content data for Thai red chillies named Jinda at different temperatures and evaluate the ability of six commonly used equilibrium moisture content-equilibrium relative humidity (EMC-ERH) models to fit the data obtained. The equilibrium moisture content of Thai red chillies was determined at $32.2^{O}C$, $48.9^{O}C$ and $68.3^{O}C$ by static method with 11.1% - 96.5% relative humidity. Six common models were applied to analyze the experimental data. It was found that the equilibrium moisture content can be predicted by Modified Halsey model.

Keywords : *Red chilli, Equilibrium moisture content, Sorption isotherm, Modeling.*

1. INTRODUCTION

The chili pepper is a fruit of plant belonging to Capsicum genus. It is one of the most used spices of garnishing dishes. It is used as basic ingredient in everyday cuisine all over the world. The consumption of chilli pepper by Thai, Indian, Mexican and American people is about 5.0 g/person/day, 2.5 g/person/day, 20.0 g/person/day and 1.5 mg/person/day respectively. Chillies are used for coloring spice by the needs of the consumers. It is a short rotate plant which can be used in both fresh and preserved form. Thailand produces large number of chilli each year but it still needs to improve its quality from its production in farms to dinning table. Thailand exports fresh, sauce and dried chillies for about 900 million baht a year [1]. Since 1997, it has been exporting more than 10,000.0 ton each year. In year 2001, the exported quantity was 12,283.0 ton. The exported number increases each year. Dried chillies are also exported every year as 51.0-92.0 million baht. However, Thailand also imports dried chillies from other countries. In year 1997, 4,642.0 ton of dried chillies were imported. This shows that the consumption of chillies will increase whereas the quality is not consistent to it.

Various types of chilli pepper exist in Thailand. These peppers, popular in Asian cooking, especially stir-fry dishes are very hot (80,000 to 300,000 Scoville units). The most famous one is "prig kee nu". It is small pepper in green and red color. Thai red chillies have 87.0-90.0 mg/100g of vitamin C and 140.8 RE of β-carotene. It is good for blood vessels expansion at the intestines and stomach as it can help to absorb the nutrient well. Thai red chillies named Jinda are a very hot and tiny. It is 3-4 cm long which is usually dried in the sun.

Air is the most commonly used gas for drying foods and the humidity content is important when predicting the drying conditions. When air is brought in contact with a wet product, equilibrium between the air and product is eventually reached. The moisture of the product under such a condition is called the equilibrium moisture content. In addition, the storage conditions of Thai red chillies have a substantial influence on its viability and longevity. It is necessary to investigate the equilibrium moisture content relationships of Thai red chillies at various relative humidity at constant

temperatures and pressure. It is expressed by the sorption isotherms. The adsorption isotherm data can be used for establishing a storage method, while the desorption isotherms data are useful for the drying analysis. The development of equilibrium moisture content model is essential for the establishment of humidity boundaries to inhibit microorganism. The equilibrium moisture content models are very important for the design and optimization of drying equipment, drying processes modeling, prediction of shelf-life stability, and calculation of moisture change which may occur during storage and selecting appropriate packaging materials [2] and it is necessary to investigate the equilibrium moisture content in wide range of relative humidity. Several empirical and semi-empirical equations have been proposed for the sorption isotherms of agricultural and food products. However, no single equation is general enough to predict the relationship between the equilibrium moisture content of the products and the relative humidity. [3, 4]

The specific objectives of this study were to establish the experimental equilibrium relative humidity-equilibrium moisture content data for Thai red chillies named Jinda at different temperatures and evaluate the ability of six commonly used EMC-ERH models to fit the data obtained.

2. MATERIALS AND METHODS

Fresh Thai red chillies used in this study were purchased from the local market at Phitsanulok province, Thailand.

In this study, the static gravimetric method, which is based on the use of saturated salt solutions to maintain a selected relative humidity when the equilibrium will be reached, was used. The mass transfers between the product and ambient air are saturated by natural diffusion of water vapor. The atmosphere surrounding the product has a fixed air moisture content for every temperature applied to the salt solution [5]. The samples were sealed up in small glass containers with base diameter of 9 cm and height of 17.5 cm which contained saturated salt solutions. The salt solutions used and corresponding relative humidity at different temperature are given in table 1 [6].

Table 1 Relative humidity exhibited by saturated salt solutions at different temperature.

Salt	Relative humidity (RH), %		
	32.2^OC	48.9^OC	68.3^OC
LICl	11.9	11.5	11.1
$MgCl_2 6H_2O$	32.6	31.6	30.3
$Mg(NO_3)_2 6H_2O$	51.9	47.3	42.2
NaCl	75.6	74.8	73.2
$(NH_4)_2SO_4$	80.0	79.1	78.0
KNO_3	90.0	85.3	78.0
K_2SO_4	96.5	95.8	95.0

The glass containers with the sample and saturated salt solutions inside were put in a hot air oven to maintain the temperature. When the moisture content of the chillies reached equilibrium with relative humidity of the atmosphere maintained in the glass container, the equilibrium moisture content of the sample was calculated on dry basis from the weight change and dry matter weight. All experiments were replicated three times and the average values were used in the analysis.

The equilibrium moisture content data of Thai red chillies were fitted to the six moisture sorption isotherm models as follows:

Halsey model [7]

$$RH = \frac{1}{\left[\dfrac{(A + BT)}{M}\right]^C + 1} \tag{1}$$

$$M = (A + BT)\left[\frac{RH}{1 - RH}\right]^C \tag{2}$$

Modified Henderson model [8]

$$RH = 1 - \exp[-A(T + B)M^C] \tag{3}$$

$$M = \left[\frac{-\ln(1 - RH)}{a(T + b)}\right]^{1/C} \tag{4}$$

Modified Halsey model [9]

$$RH = \exp\left[\frac{-\exp(A + BT)}{M^C}\right] \tag{5}$$

$$M = \left[\frac{-\exp(A + BT)}{\ln(RH)}\right]^{1/C} \tag{6}$$

Modified Oswin [10, 11, 12, 13]

$$RH = \frac{1}{\left[\frac{(A + BT)}{M}\right]^C + 1} \tag{7}$$

$$M = (A + BT)\left[\frac{RH}{1 - RH}\right]^C \tag{8}$$

Modified BET model [14, 15]

$$M = \frac{(A + BT) \cdot C(RH)}{(1 - RH)\left[1 - RH + C(RH)\right]} \tag{9}$$

$$M_m = A + BT \tag{10}$$

Where M_m is the monolayer moisture content. The BET is valid for RH<0.5

Modified Smith model [16]

$$RH = \exp\left[\frac{(A + BT) - M}{C + DT}\right] - 1 \tag{11}$$

$$M = (A + BT) - (C + DT)\ln(1 - RH) \tag{12}$$

Where *M* is the equilibrium moisture content in %d.b., *RH* is the equilibrium relative humidity in decimal, A, B,C and D are model coefficients, and T is the temperature in ^{O}C.
The statistical parameter mean relative error (MRE) as a % and standard error of estimate (SEE) were used to determine the quality of the fit.

$$MRE = \frac{100}{N} \sum_{i=1}^{N} \left| \frac{M_{i,\exp} - M_{i,pre}}{M_{i,\exp}} \right| \tag{13}$$

$$SEE = \sqrt{\frac{\sum_{i=1}^{N} (M_{i,\exp} - M_{i,pre})^2}{d_f}} \tag{14}$$

$$R^2 = \frac{\sum_{i=1}^{N} (M_{i,pre} - \overline{M})^2}{\sum_{1=1}^{N} (M_{i,\exp} - \overline{M})^2} \tag{15}$$

Where $M_{i,exp}$ is the ith experimental moisture content, $M_{i,pre}$ is the ith predicted moisture content, N is the number of data points, and d_f is the number of degrees of freedom of regression model. [17] In general, larger value of R^2, and small values of MRE and SEE, associated with randomly residual distributions indicate good fitting ability.

3. RESULTS AND DISCUSSION

The equilibrium moisture content (EMC) at 32.2°C, 48.9°C and 68.3°C with relative humidity between 11.1% - 96.5% were determined and used to estimate the parameters in the expressions of the moisture sorption isotherm models by using the non-linear regression procedure solving with STATISTICA 6.0 in order to investigate the relation between EMC, temperature and relative humidity. The regression analysis was repeated several times with different initial values above and below those calculated to confirm the validity of the regression parameters. The coefficients of the Halsey, Modified Henderson, Modified Halsey, Modified Oswin, Modified BET, and Modified Smith with their static mean relative error (MRE) and standard error of estimate (SEE) are presented in Table 2. The observed and predicted sorption isotherms using six models are shown in Fig.1. The results indicate EMC increases when temperature decreases with constant ERH. At constant temperature, the EMC increases with increasing ERH. For a wide range of temperature and relative humidity, the six models can be accepted as the values of R^2 are more than 0.8. The Modified Oswin model can be accepted for high temperature range. Its MRE, R^2 and SEE values are 26.76 %, 0.986 and 4.94 respectively. It can be seen that the EMC data were best fitted by Modified Halsey model, with MRE of 26.54 %, R^2 of 0.98 and SEE of 4.88. The residual plot distributions for Modified Halsey model showing data points not far scattered from zero as shows in Fig.2. This indicates that the appropriate model should be as the following:

$$M = \left[\frac{-\exp(4.15398 - 0.00536T)}{\ln(RH)} \right]^{1/1.61421} \tag{16}$$

Table 2 Predicted parameters and comparison criteria for EMC models of Thai red chillies.

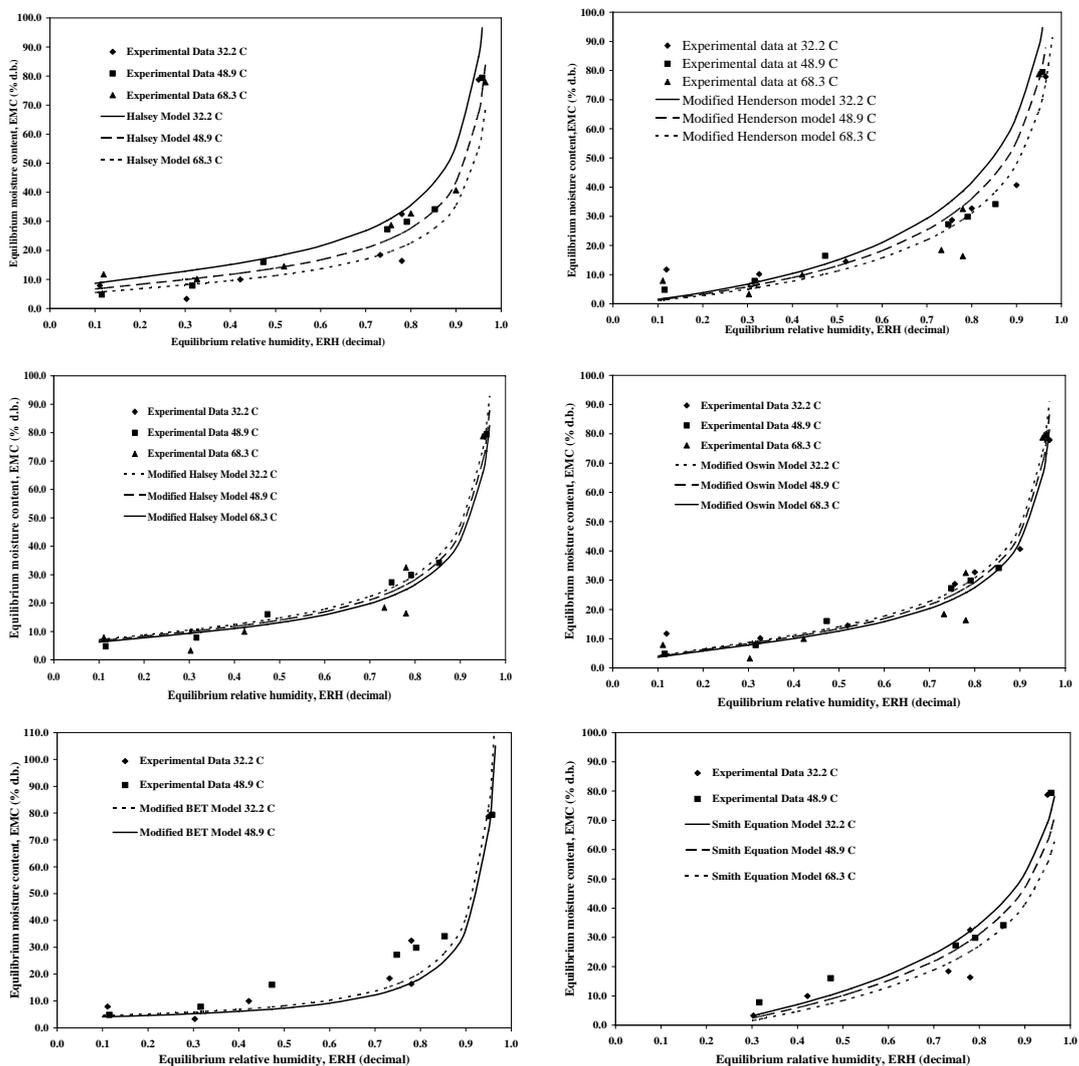| EMC models	Parameters and criteria						
	A	B	C	D	MRE,%	SEE	R^2
Halsey	2607.797	1.65036	-	-	40.01	10.83	0.96
Modified Henderson	0.00056	101.0631	0.8235	-	30.08	8.37	0.94
Modified Halsey	4.15398	-0.00536	1.61421	-	26.54	4.88	0.98
Modified Oswin	15.45423	-0.04166	0.56241	-	26.76	4.94	0.98
Modified BET	4.94088	-0.02589	554740.8	-	32.30	8.48	0.95
Modified Smith	-12.8084	0.2198	129.1178	-0.1274	29.22	7.34	0.96

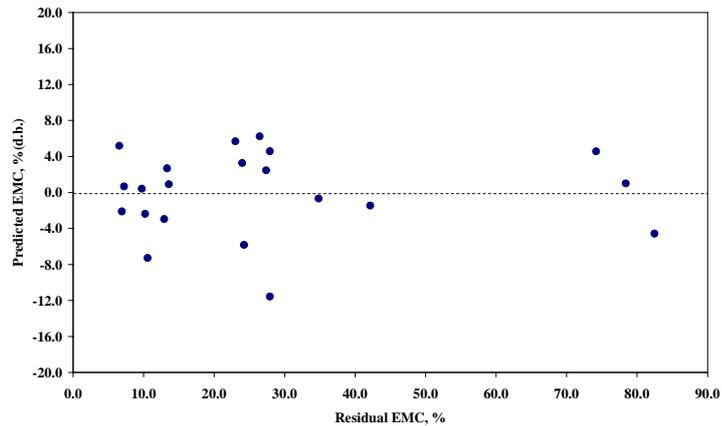Fig. 1 EMC of Thai red chillies at various temperatures by six models.

Fig. 2 Plots of residual EMC by Modified Halsey model
vs predicted EMC for Thai red chillies.

4. CONCLUSIONS

The equilibrium moisture content had been obtained at $32.2^{O}C$, $48.9^{O}C$ and $68.3^{O}C$, giving data used to determine the appropriate model for predicting the EMC of Thai red chillies named Jinda for known temperature values and relative air humidity by fitting with six models. The six common model, namely Halsey, Modified Henderson, Modified Halsay, Modified Oswin, Modified BET and Modified Smith were found acceptable for predicting EMC. However, the Modified Halsey model, which gave the lowest MRE and SEE and highest R^2 was considered to be the most suitable model for describing the relation between the EMC , ERH and temperature, followed by the Modified Oswin model which will be useful for establish the drying model and storage method of Thai red chillies.

Acknowledgement

References

[1] Department of Agricultural Extension Thaialnd (2006). Data from Data Knowledge Base.
[2] Gal, S. (1987). The need for, and practical applications of sorption data. In R. Jowitt,
    F.Escher, B. Hallstrom, H.Mefert, W.Spiess,& G.Vos(Eds.). Physical properties of foods
    (pp. 13-25). London: Elksevier Applied Science.
[3] Brooker D B, Arkena F W B, Hall C W (1974), Drying Cereal Grains. The Avi Publish Company,
    Connecticut.
[4] Lahsasni S, Kouhila M, Mahrouz M (2004). Adsorption-desorption isotherms and heat of sorption
    of prickly pear fruit (Opuntia ficus indica). Energy Conservation and Management. 45(2). 249-
    261.
[5] Wolf, W., Spiess, W.E.L., Jung, G. (1985). Standardization of isotherm measurement
    (COST project 90 and 90 bis). In:Simatos, D., Multon, J.L. (Eds). Properties of Water in Foods.
    Martinus Nijhoff Publishers. Dordrecht. The Netherlands. 661-679.
[6] Soponronnarit, S. (1997). Drying of Grain and Food, King Mongkut's University of Technology
    Thonburi, Bangmod, Bangkok, Thailand. 67.
[7] Halsey G (1984). Physical adsorption on non-uniform surfaces. Journal of Chemical Physics.
    16(10). pp. 931-937.

[8] Thopson H.L. (1972). Temporary storage of high moisture shelled corn using continuous aeration. Transactions of the ASAE, 15(2), 333-337.

[9] Iglesias H.A. and Chirife J. (1976a). Prediction of the effect of temperature on water sorption Isotherms of food materials. J. Food Technon 11. 910-917.

[10] Chen C (1988). A study of equilibrium relative humidity for yellow-dent kernels. PhD Thesis,University of Minisota, St.Paul, USA.

[11] Chen C; Morey R V (1989a). Comparison of flour EMC/ERH equations. Transactions of the ASAE. 32(3). 983-990.

[12] Chen C; Morey R V (1989b). Equilibrium relative humidity relationships for yellow-dent Corn. Transactions of the ASAE. 32.

[13] Chen C (2000). A rapid method to determine the sorption isotherms of peanuts. Journal of Agricultural Engineering Research. 75. 401-408.

[14] Brunauer, S., Emmett, P.H., & Teller, E. (1938). Adsorption of gasses in multi-Molecular layers. Journal of American Chemical Society. 60, 309-319.

[15] Iglesias, H., and Chirfe, J. (1976b). BET monolayer values in dehydrated foods and food components. Lebeusmittel-Wissenschaft und Technologie. 9. 107-113.

[16] Rockland L B and Stewart GF (1981). Water Activity Influence on Food Quality. New York: Acedemic Press.

[17] L. Ait Mohamed, et.al. (2005). Moisture sorption isotherms and heat of sorption of bitter orange leaves (Citrus aurantium). Journal of Food Engineering. Vol.67. 491-498.