International Journal of Scientific Engineering and Technology (ISSN : 2277-1581)
Volume No.4 Issue No.2, pp : 40-44 01 Feb. 2015

Mathematical Modeling of Equilibrium Moisture Content of Local Cardamom (*Amomum cardamomum Wild*)

Sigit Triwahyudi[1], Budi Rahardjo[2], Leopold O. Nelwan[3] and Dyah Wulandani[3]
[1]Indonesian Center for Agricultural Engineering Research and Development, Tromol Pos 2, Serpong, Tangerang, Banten 15310 Indonesia
[2] Department of Agricultural Engineering, Faculty of Agricultural Technology, Gadjah Mada University, Jl. Sosio Justisia, Bulaksumur, Yogyakarta - 55281, Indonesia
[3] Department of Agricultural Engineering, Bogor Agricultural University, PO Box 220 Bogor16002, Indonesia
E-mail : sigittriwahyudi@yahoo.com

Abstract: The objective of this work was done to investigate the effect of temperature and relative humidity on the equilibrium moisture content (EMC) of local cardamom (Amomum cardamomum Wild) and to get the appropriate mathematical models. The EMC of local cardamom were determined by dynamic method using laboratory air dryer at the temperature of 40, 50 and 60^{0}C and at the relative humidity of 20, 40 and 60%. Four widely used three parameters sorption isotherms equations such as modified Henderson, modified Chung–Pfost, modified Oswin and modified Halsey were used to fit the experimental data. The accuracy of the model was evaluated by comparing the value of the coefficient of determination (R^2) and the value of the root mean square error (RMSE) between the experimental and the predicted value of EMC by using nonlinear regression analysis. The effects of relative humidity were found to significantly influence the EMC. Based on statistical analysis the modified Chung-Pfost equation have the highest value of R^2 = 0.979 and the lowest value of RMSE = 0.758, it can be seen that the modified Chung-Pfost equation has the ability to properly describe EMC of local cardamom on a selected range of temperature and relative humidity.
Keywords: Equilibrium moisture content; dynamic methode; mathematical modelling; local cardamom

I. Introduction

Local cardamom (*Amomum cardamomum* Wild or *Amomum compactum* soland ex Maton) is native to Indonesia and endemic plants in hilly area in western Java. Now grown and may be wilder in various places, Local cardamom mainly produced commercially from West Java and southern Sumatra. Cardamom is a fruit that is often used as spices (seasonings) for certain dishes and also for a mixture of herbs. Local cardamom was reported contains 2 – 5% of essential oil comprising mainly 1,8% cineol (up to 70%) and β-pinene (16%) (Lim, 2013), α-pinene, α-terpineol and humulene were also found. During heating these components will evaporate along with the water vapour at a temperature below the boiling point. According to Ketaren (1985) the recommended temperature for drying spices was maximum of 60^{0}C, while drying temperature for cardamom was not above 50^{0}C (Ali, 2007).

The fresh local cardamom capsules contain about 70 – 80% moisture (on wet basis) depending upon the maturity level of the capsules at time of plucking (Rao *et al*., 2001). Because of high water content, local cardamom should be quickly processed to reduce the risk of damage. Dehydration of foods is one of the most common processes used to improve food stability, since it decreases considerably the microbiological activity and minimizes physical and chemical changes during it storage (Babetto *et al*., 2011). Also, it extends the shelf-life with sensorial characteristics similar to those of fresh products (Sacilik & Unai, 2005).

The concept of equilibrium moisture content is an important factor in the process of drying of agricultural products. Equilibrium moisture content can be used to determine the drying time for these commodities, structures and components for the dryer, and the cost required for the drying process (Akanbi *et al*,. 2006; Chowdhury *et al*., 2006)

According to Bala (1997), there are two ways or methods to determine the equilibrium moisture content is a static method and dynamic method. In the static method the sample is allowed to come to equilibrium in still moist air, usually a chemical solution used to maintain a stable RH environmental. In order to achieve equilibrium may take several days. In the dynamic method requires a mechanism movement of air flow, this way is faster, but has disadvantage in its RH control. Dynamic methods commonly used in the analysis of drying process while the static method for the analysis of storage.

Many researchers have developed a mathematical equation, theoretical, semi-theoretical and empirical sorption isotherm to describe the groceries. Four commonly used equation is modified Henderson, modified Chung-Pfost, modified Halsey and modified Oswin (Chowdhury *et al*., 2006; Aviara *et al*., 2006; Arabhosseini *et al*., 2010; Raji and Ojediran, 2011, Argyropoulos *et al*., 2012; Chenarbon *et al*., 2012) as shown in Table 1. The equation has been adopted as standard equations by the American Society of Agricultural Engineers (ASAE) to describe the sorption isotherms (ASAE, 1999).

According to the Sun and Woods (1997), modified Chung-Pfost equation and modified Oswin equation is most suitable for grain products. Meanwhile, according to Sitompul *et al*.

(2000a), modified-Henderson and modified Oswin equation is an equation that is suitable for grain corn products. Selection of EMC equation with two parameters has been carried out by Sitompul *et al*. (2000b). However, the correlation of the two parameters EMC failed to give a good correlation compared with the correlation of the three parameters (Sitompul *et al*., 2000c)

In our knowledge, no information is available about equilibrium moisture content of local cardamom (*Amomum cardamomum* Wild). Therefore, in the present study, mathematical modelling of equilibrium of local cardamom was investigated. The main objectives of the present work were: to study the effect of different parameter (temperature and relative humidity of drying air), on the equilibrium moisture content of local cardamom. In addition, development of a mathematical modelling for EMC of local cardamom and choosing a suitable model. Information derived from this study will enable us to design an appropriate dryer and to make recommendation on optimal drying condition for local cardamom.

II. Material and Methodology

2.1. Drying equipment

The drying experiments were carried out by using the laboratory dryer in the Department of Agricultural Engineering, Faculty of Agricultural Technology, Bogor Agricultural University of Indonesia. The laboratory dryer was similar to that described by Manalu *et al*. (2010), which could be regulated to any desired drying air temperature between 30 and 80^{0}C and relative humidity between 20 and 90%. The air temperature and the relative humidity are controlled by AVR Atmel microprocessor controller with temperature accuracy of ±1^{0}C and relative humidity accuracy of ±2%. The unit is equipped with a 2000 W steam injection humidifier, a 2000 W heating and heating control unit, an electrical fan, temperature and humidity measurement sensor by SHT15 Sensirion and the 40 cm x 40 cm x 40 cm drying chamber. A schematic diagram of this laboratory dryer is shown in Figure. 1.

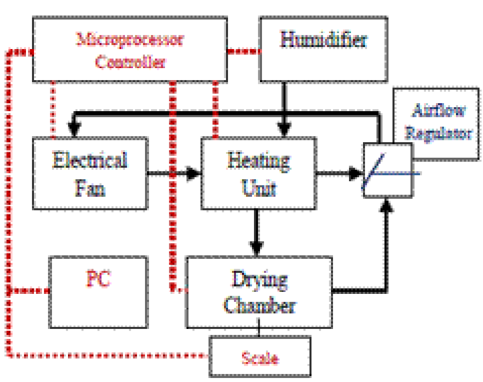

Figure 1. Schematic diagram of exprimental set-up

The desired drying air temperature and relative humidity were maintained by PID control system. The air passed from the heating unit at the desired temperature and passed to the drying chamber. The lever manual-controller regulates the velocity of the drying air flowing through the drying chamber and it was measured by a hot wire digital Kanomax anemometer with the accuracy of ±0.1 m/s. The drying air temperature and relative humidity were measured directly in the drying chamber. Weighing of samples inside the drying chamber was done automatically at desired time interval using an electronic balance by GF-3000 AND with a capacity of 0 – 3000 g and accuracy of 0.01 g. The dryer has been equipped with data acquisition system.

2.2. Experimental procedure

Drying experiments were conducted at the drying air temperatures of 40, 50 and 60^{0}C and relative humidities of 20%, 40% and 60% by using the laboratory dryer. The drying air velocity was maintained at 0.6m/s. Prior to an experiment, the laboratory dryer was allowed to run at least for one hour to obtain a steady drying air condition and was maintained for the duration of the test. For each experiment, about 100 g of local cardamom was placed in the drying tray. The air temperature, air relative humidity and sample weight were continuously monitored and recorded every 5 min during drying experiments. Drying was continued until the samples reached a constant weight. After each drying experiment, the sample was oven-dried at 103 ± 2^{0}C to determine the moisture content (Kashaninejad *et al.*, 2007). The final moisture content from this experiments is the equilibrium moisture content (EMC) of local cardamom.

To select a suitable model for describing the EMC of local cardamom, EMC obtained from the drying experiment were fitted to four widely used desorption isotherm models (Table 1) by using non-linear least squares regression solved by a Levenberg-Marquardt numerical method in IBM SPSS Statistics 19.

Table 1. Equilibrium moisture content models used for fitting the experimental data

No.	Model	Equation
1	Modified Henderson	EMC = $[\ln(1\text{-ERH}) / \text{-A} (T+B)]^{1/C}$
2	Modified Chung-Pfost	EMC = $-1/B \ln[-(T+C)/A \ln(\text{ERH})]$
3	Modified *Halsey*	EMC = $[-\exp(A+BT) / \ln(\text{ERH})]^{1/C}$
4	Modified *Oswin*	EMC = $(A+BT) [\text{ERH} / 1\text{-ERH}]^{1/C}$

The coefficient of determination (R^2) was one of the main criteria for selecting the best eqution. In addition to R^2, the goodness of fit was determinated by root mean square error (RMSE). For the best fit, the R^2 value should be high and RMSE value should be low (Chowdhury *et al.*, 2006). R^2 and RMSE are defined as:

$$R^2 = 1 - \frac{\sum_{i=1}^{N}\left(EMC_{Exp,i} - EMC_{pred,i}\right)^2}{\sum_{i=1}^{N}\left(EMC_{Exp,i} - \overline{EMC}_{Exp}\right)^2} \qquad (1)$$

$$RMSE = \sqrt{\frac{\sum_{i=1}^{N}\left(EMC_{Exp,i} - EMC_{pred,i}\right)^2}{N}} \qquad (2)$$

where $EMC_{exp,i}$ and $EMC_{pre,\,i}$ *are* the experimental and predicted equilibrium moisture content (% db), respectively and N is the number of observations.

III. Results and Discussion

Experimental value of equilibrium moisture content of local cardamom at various temperatures and equilibrium relative humidity of the drying air are listed in Table 2.

Tabel 2. Experimental result equilibrium moisture content of local cardamom at different drying conditions

Temperature °C	ERH (decimal)	EMC (% db)
	0.2	-
40	0.4	11.887
	0.6	15.130
	0.2	-
50	0.4	9.773
	0.6	13.650
	0.2	2.208
60	0.4	8.004
	0.6	-

According to the results, the temperature and equilibrium relative humidity (ERH) have considerable effect ~~on~~ equilibrium moisture content. The higher drying air temperature resulted the lower the equilibrium moisture content and otherwise. In contrast to the temperature, the higher the ERH of the air drying, equilibrium moisture content will be higher as well and otherwise. To achieve lower equilibrium moisture content required a higher temperature and lower of ERH air drying. The increase in temperature causes an increase in the amount of water that evaporates and reduces the amount of water absorbed at constant ERH. Similar results were also reported by Chowdhury *et al*., (2006), to determination of the equilibrium moisture content of green beans and Saeed *et al*., (2008) for Rosella.

In this study, the ERH is a more significant factor in determining of the EMC (p = 0.023) compared with the drying air temperature (p= 0.144). This agrees with research conducted by Jayas *et al*., (1991) which states that the relative humidity of the drying air has a significant effect on final grain moisture content to control the rate of transport of water vapour from the air to the grain surface and affect the equilibrium moisture content.

The data in Table 2 are used to determine the model of equilibrium moisture content (EMC) of local cardamom based model as shown in Table 1. The model equations solved using non-linear regression with IBM SPSS Statistics 19 programme. Modelling results can be seen in Table 3. While the equation coefficients and statistical comparisons for all four models of equilibrium moisture content can be seen in Table 4.

Table 3. Experimental and predicted of equilibrium moisture content of local cardamom

Temp. °C	ERH (decimal.)	EMC (Experimental)	Mod. Henderson	Mod. Chung-Pfost	Mod. Halsey	Mod. Oswin
40	0.4	11.887	10.733	11.321	10.857	10.969
40	0.6	15.130	16.154	15.895	16.251	16.148
50	0.4	9.773	8.912	9.163	8.830	9.064
50	0.6	13.650	13.413	13.737	13.216	13.343
60	0.2	2.208	4.311	3.064	4.867	4.484
60	0.4	8.004	7.696	7.473	7.181	7.159

Tabel 4. Estimated value of coefficient equations and statistical evaluation of equilibrium moisture content model of local cardamom

Equation Models	R^2	RMSE	Coefficient		
			A	B	C
Modified Henderson	0.933	1.348	0.001	-7.154	1.429
Modified Chung-Pfost	0.979	0.758	122.594	0.128	-8.500
Modified Halsey	0.901	1.638	-0.030	1.449	4.565
Modified Oswin	0.926	1.416	22.555	-0.231	2.097

From Table 4 it can be seen that the correlation coefficient (R^2) for the regression results of several models of the EMC has a high values ($R^2 \geq 0.900$) , it shows that all four models of the EMC can describe well the equilibrium moisture content for the local cardamom . Chung - Pfost modified model has a highest value of coefficient of determination (R^2) = 0.979 and the lowest value of root mean square error (RMSE) = 0.758, followed by a modified Henderson, modified Oswin and modified Halsey respectively. Thus the model modified Chung - Pfost equation is the most appropriate model to predict the equilibrium moisture content for the local cardamom, in the temperature range of 40 - 60^{0}C and RH from 20 to 60%. According to Chen and Morey (1989), modified Chung - Pfost models and modified Henderson was a suitable model to predict the equilibrium moisture content for seeds and fibrous material. Chung - Pfost modified model was also used by Phoungchandang and Wongwatanyoo (2010) to predict the equilibrium moisture content of carrot slices at a temperature range of 40 - 60^{0}C and relative humidity between 19.8 to 49.8 % , with a R^2 of 0.996 . Li (2012) also used a modified Chung - Pfost method to predict the equilibrium moisture content of wheat grains at a temperature ranging from 10 to 35^{0}C and relative humidity between 11.3 to 96 %, with a R^2 of 0.993

EMC modelling equation for the local cardamom using a modified Chung-Pfost models are as follows:

$$EMC = -1/0{,}128 \ln [- (T - 8{,}499)/122{,}594 \ln(ERH) \quad (3)$$
for $40^0C \leq T \leq 60^0C$ and $0.2 \leq ERH \leq 0.6$, $R^2 = 0.979$

The accuracy of the established model for the equilibrium moisture content also was evaluated by comparing the predicted EMC with experimental EMC. The performance of the four model at different drying condition has been illustrated in Figure 2. As shown in the figure, the modified Chung-Pfost model provided a good conformity between experimental and predicted EMC, the dots in this model are nearly coinciding around at a 45^0 straight line, which indicates that the model could adequately describe the EMC of local cardamom.

Figure 3 shows a comparison between the experimental and predicted of equilibrium moisture content using the modified Chung-Pfost models. Based on the graph, drying conditions for local cardamom is recommended on the temperature of 40^0C at 40% RH or temperature of 50^0C at 40 and 60% RH, to achieve a final moisture content of between 11-13% db (10-12% wb).

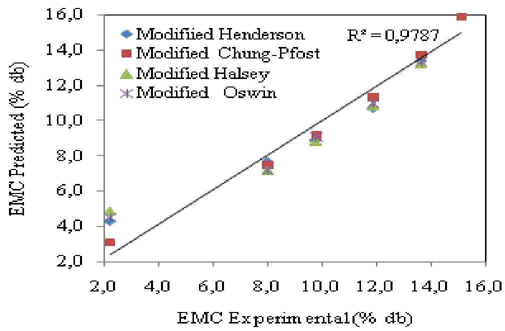

Figure 2. Comparison of experimental and predicted EMC values at different drying conditions for the selected model.

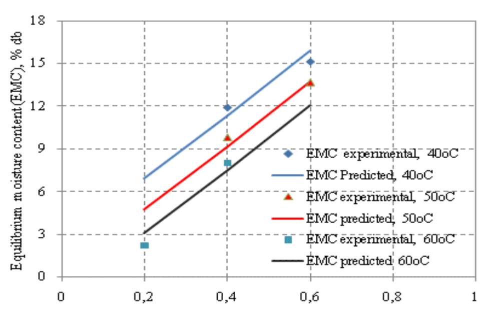

Figure 3. Experimental and predicted value of equilibrium moisture content of local cardamom by modified Chung-Pfost at temperature of 40, 50 and 60^0C.

IV. Conclusion

Based on the research results, it can be drawn conclusions as follows:

1. Equilibrium relative humidity was significant factors in determining of equilibrium moisture content (EMC) of local cardamom compared to the air drying temperature.
2. The modified Chung-Pfost model produced the highest value of the coefficient of determination (R^2 = 0.979) and the lowest value of RMSE = 0.578, and it could be used sufficiently to describe the EMC of local cardamom in the range of the test drying conditions (temperature ranging 40 – 60^0C and relative humidity ranging 20 - 60%).
3. Recommended drying conditions for local cardamom was at drying temperature of 40^0C and 40% relative humidity or at temperatures of 50^0C at relative humidity of 40 and 60% to achieve the final moisture content of between 10-11% wb (12-13%% db).

References

i. *Akanbi, C.T., Adeyemi, R.S. & Ojo, A., 2006. Drying characteristics and sorption isotherm of tomato slices. Journal of Food Engineering, 73(2), p.157 – 163.*

ii. *Ali, S.A., 2007. Cardamom processing. Practical action technical brief. [Online] Practical Action Available at: http://www.practicalaction.org/technical_information_service/ [Accessed Oktober 21 , 2008].*

iii. *Arabhosseini, A., Huisman, W. & Mu ller, J., 2010. Modeling of the equilibrium moisture content (EMC) of Miscanthus (Miscanthus-giganteus). Biomass and Bioenergy , 34, pp.411 - 416.*

iv. *Argyropoulos, D., Alex, R., Kohler, R. & Müller, J., 2012. Moisture sorption isotherms and isosteric heat of sorption of leaves and stems of lemon balm (Melissa officinalis L.) established by dynamic vapor sorption. LWT - Food Science and Technology , 47, pp.324 - 331.*

v. *ASAE, 1999. Moisture relations of plant-based agricultural products. ASAE STANDARDS D245.5, OCT95. pp.512 -528.*

vi. *Aviara, N.A., Ajibola, O.O., Aregbesola, O.A. & Adedeji, M.A., 2006. Moisture sorption isotherms of sorghum malt at 40 and 50°C. Journal of Stored Products Research , 42, pp.290 - 301.*

vii. *Babetto, A.C., Freire, F.B., Barrozo, M.A.S. & Freire, J.T., 2011. Drying of garlic slices: Kinetics and nonlinearity measures for selecting the best equilibrium moisture content equation. Journal of Food Engineering, 107, pp.347 - 352.*

viii. *Bala, B.K., 1997. Drying and Storage of Cereal Grain. New Delhi, India: Oxford and IBH Publishing Co. PVT.LTD.*

ix. *Chenarbon, H.A. et al., 2012. Moisture Sorption Isotherms of Rosemary (Rosmarinus officinalis L.) Flowers at Three Temperatures. American-Eurasian J. Agric. & Environ. Sci., 12(9), pp.1209 - 1214.*

x. *Chen, C.C. & Morey, R.V., 1989. Comparison of four EMC/ ERH equations. Transactions of the ASABE, 32(3), pp.983 - 990.*

xi. *Chowdhury, M.M.I., Huda, M.D., Hossain, M.A. & Hassan, M.S., 2006. Moisture sorption isotherms for mungbean (Vigna radiata L). Journal of Food Engineering , 74, pp.462 - 467.*

xii. *Kasaninejad, M., Mortazavi, A., Safekordi, A. & Tabil, L.G., 2007. Thin-layer drying characteristics and modeling of psitachio nuts. Journal of Food Engineering, 78, pp.98 - 108.*

xiii. *Ketaren, S., 1985. Pengantar teknologi minyak atsiri. Jakarta: Balai Pustaka.*

xiv. *Li, X., 2012. The Hygroscopic Properties and Sorption Isosteric Heats of Different Chinese Wheat Types. Journal of Food Research, 1(2), pp.82 -98.*

xv. *Lim, T.K., 2013. Amomum Compactum. In Edible Medicinal and Non-Medicinal Plants. Dordrecht: Springer Sciences & Busines Media. pp.797 - 800.*

xvi. *Manalu, L.P., Tambunan, A.H., Nelwan, L.O. & Hoetman, A.R., 2010. Analisis energi dan eksergi pengeringan lapisan tipis temu putih. Jurnal Imiah Teknologi Energi, 1(9).*

xvii. *Phoungchandang, S. & Wongwatanyoo, J., 2010. Desorption Isotherms and Drying Characteristics of Carrot Using Tray and Heat Pump-Assisted Dehumidified Drying. KKU Res J, 15(3), pp.171 - 186.*

xviii. *Raji, A. & Ojediran, J.O., 2011. Moisture sorption isotherms of two varieties of millet. Food and Bioproducts processing, 89, pp.178 - 184.*

xix. *Rao, V.G., Mande, S. & Kishore, V.V.N., 2001. Study of drying characteristics of large-cardamom. Biomass and Bioenergy, 20, pp.37 - 43.*

xx. *Sacilik, K. & Unai, G., 2005. Dehydration characteristics of Kastamonu garlic slices. Biosystems Engineering , 92(2), p.201 – 215.*

xxi. *Saeed, I.E., Sopian, K. & Zaino- Abidin, Z., 2008. Drying characteristics of Roselle (1): Mathematical Modeling and Drying Experiments. Agricultural Engineering International: the CIGR Ejournal Manuscript FP 08 015, 10, pp.1 - 25.*

xxii. *Sitompul, J.P., Istadi & Sumardiono, S., 2000a. Non-Linear Parameter Estimation of EMC Correlations for Grain-Type Agricultural Products. In International Conference On Fluid and Thermal Energy Conversion, Proceedings Institut Teknologi Bandung. Bandung, 2000. Lembaga Penelitian ITB.*

xxiii. *Sitompul, J.P., Sumardiono, S., Istadi & Sasmojo, S., 2000b. Korelasi dan Prediksi Kandungan Air Setimbang Produk Pertanian Berbentuk Butiran. In Prosiding Seminar Nasional Teknologi Proses Kimia II. Jakarta, 2000*

xxiv. *Sitompul, J.P., Istadi & Sumardiono, S., 2000c. Pemilihan KorelasiI Kandungan Air Setimbang (tiga parameter)untuk Produk Pertanian Padi. In Proceding of Nat'l Seminar on Agricultural Engineering (AE2000). Bogor, 2000.*

xxv. *Sun, D.W. & Woods, J.L., 1977. Deep-bed Simulation of the Cooling of Stored Grain with Ambient Air: a Test Bed for Ventilation Control Strategies. Journal of Stored Products Research, 33(4), pp.299 - 312.*