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Temperature and relative humidity effect on equilibrium moisture content of cassava pulp

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Abstract: The purpose of this research was to study the effect of temperature and relative humidity on the equilibrium moisture content of cassava pulp. In experiments, cassava pulp was tested with a static method that controlled the temperature at 30, 50 and 70°C and controlled relative humidity in a range 10–90% with standard saturated salt solutions as LiCl, $MgCl_2$, NaBr, NaCl and KNO_3. Five equations of equilibrium moisture isotherm were analysed to predict the equilibrium moisture content, which was a guideline to develop a new isotherm equation. The experimental results showed that the equilibrium moisture content was increased with increased relative humidity whereas it decreased with increased drying temperature. Therefore, the drying process and storage method of cassava pulp must control temperature and relative humidity of no more than 50°C and 60%, respectively. The analysis of isotherm equations revealed that the new isotherm equation has high accuracy to predict the equilibrium moisture content of cassava pulp and higher R^2 correlation with the experimental data than five isotherm equations.

Keywords: agri-product storage; food processing; microbiological stability; isotherm; tapioca

Cassava, or tapioca, which is known biologically as *Manihot esculenta* Crantz, is one of the important economic crops and the major export crop of Thailand. Even though the major world producers of cassava are Nigeria, Brazil, Indonesia, Thailand and Congo (Poramacom et al. 2013), Thailand, Indonesia and Brazil are the most prominent exporters of cassava starch, with their production accounting for 95% of the world's supply. Thailand cassava production during 2016 gave yields of 10.675 million t of fresh roots with 7.983 million rai of cultivated area (North Eastern Tapioca Trade Association 2017). Fresh root from farms is used to produce chips and pellets (around 6.416 million t) and for starch, it is around 3.275 million t (National Science and Technology Development Agency 2012–2013). Cassava is becoming an increasingly important input for animal feed and human diet. Cassava fresh roots are processed in various ways for human's food such as chips, pellets, starch, sago, etc. However, production of cassava starch results in formation of 10 to 15% of the original processed root dry weight basis as solid waste. This waste is well known as "pulp". Cassava pulp retains a high amount of carbohydrates and fibre. It can be used in processing of biomass, ethanol, animal feed and paper pulp. On the other hand, cassava pulp still retains high moisture content – approximately 60–75% wet basis (Ukita et al. 2006); if discarded to the environment and not stored properly, it may cause environmental problems such as strong and offensive putrefaction odour and local water contamination (Djuma'ali et al. 2011). Drying the pulp would help to solve existing problems; it is primarily a process to decrease the moisture content of food to safe storage level at which spoilage caused by various reactions is reduced. This process

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can also improve stability, decrease shipping mass, reduce costs and minimize packing size requirements (Ruiz-López et al. 2008; Ehiem et al. 2016).

The main quality of food and dried products depends on physical and chemical properties and microbiological stability. These properties are essential to comply food storage regulations, food processing and to define food drying conditions to provide high quality and high stability. For example, the elephant foot yam powder drying at high temperature causes its low quality as phenolic content decreases and browning increases (Kumar et al. 2016). Other factors, such as taste, odour, appearance and texture are important to indicate food quality. The general economics of food processing such as mixing process, drying process, storage, transport and room conditioning may depend on the moisture content in food (Vasquez et al. 2011). An analysis on the moisture content of food and agriculture products is typical and important to evaluate quality, define a safe storage level and design drying methods. It may affect microbial stability because the moisture content in food is an important parameter in microorganism growth rate and survival; it is thus necessary to specify the maximum and minimum moisture content level based on the regulations of specific market and country. The equilibrium moisture content is one of the important parameters to describe storage method and drying process. The temperature and relative humidity of air are the main parameters to specify the equilibrium moisture content. Storage and food processing will prolong shelf life and drying process will increase quality if the food equilibrium moisture content can be defined. Thus, the purpose of this work is to study the effect of temperature and relative humidity on the equilibrium moisture content and to study the equilibrium moisture isotherm to predict the equilibrium moisture content of cassava pulp. The results of this study may not only help reduce the environmental problems of cassava pulp from the industry but also add value for cassava crops (Phowan, Danvirutai 2014); drying data describe the drying characteristics of cassava pulp.

MATERIAL AND METHODS

Equilibrium moisture content. The equilibrium moisture content is important for agricultural product drying process because it specifies the maximum moisture content in dried product under given drying conditions. The equilibrium moisture content depends on the relative humidity and temperature of environment as well as the product characteristics (Chong-Ho, Do-Sup 1995). The relation between the equilibrium moisture content and relative humidity at isotherm is expressed as a sigmoid curve (s-shape) or is also called "equilibrium moisture isotherm". The modified BET (Brunauer-Emmett-Teller) model was the best-fitting model to describe the sorption isotherms of pineapple in the temperature range of 20–50°C and relative humidity range of 11–97.5% (Hossain et al. 2001). The modified Henderson equation was an adequate model for the sorption data of pea seeds in the temperature range of 5–50°C and relative humidity range of 10–95% (Chiachung 2003). The GAB model was statistically suitable model for adsorption of green and roasted Yerba mate samples (Červenka et al. 2015). The Halsey model was selected as the most appropriate model for yacon bagasse powder (Carvalho Lago, Pelayo Zapata Noreña 2015). The equilibrium moisture content may be obtained by two methods – static and dynamic. In this experiment, the static method with controlled incubator and standard saturated salt solution in all isotherms was used to generate constant relative humidity in a close system. Then, the results were analysed with five equations as follows: BET, Oswin, Halsey, Henderson and Chung-Pfost. The equilibrium moisture isotherms are shown in Table 1.

Relative humidity controlling. For the examined relative humidity in closed system, mostly saturated salt solution was used, as it is convenient and low cost. Saturated salt solutions usually have good properties to control relative humidity that depends on temperature. Salt saturated solutions in this experiment were LiCl, $MgCl_2$, NaBr, NaCl and KNO_3. The initial moisture content of the cassava pulp was determined in triplicate according to the Association of Official Analytical Chemists procedures (Association of Official Analytical Chemists 1990). The cassava pulp was dried at the temperature of 30, 50 and 70°C, relative humidity was controlled by salt solution in the range of 10–90%. These experiments were tested with the static method that controlled temperature by oven and controlled relative humidity with standard saturated salt solutions as the following step. In the experiment, cassava pulp was used at ten samples of approximately 10 g each (Fig. 1a). Five prepared saturated salt solutions were

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Table 1. The equilibrium moisture isotherms

	Equation	Reference
BET	$M_{eq} = \dfrac{M_o C\mathrm{RH}}{(1-\mathrm{RH})(1+C\mathrm{RH}-\mathrm{RH})}$	Brunauer et al. (1938)
Oswin	$M_{eq} = A\left(\dfrac{\mathrm{RH}}{1-\mathrm{RH}}\right)^{n}$	Oswin (1946)
Halsey	$M_{eq} = \left(\dfrac{-A}{T\ln(\mathrm{RH})}\right)^{\frac{1}{B}}$	Halsey (1948)
Henderson	$M_{eq} = \left(\dfrac{\ln(1-\mathrm{RH})}{-AT}\right)^{\frac{1}{B}}$	Henderson et al. (1952)
Chung-Pfost	$M_{eq} = \dfrac{1}{-A}\ln\left(\dfrac{(T+B)\ln(\mathrm{RH})}{-C}\right)$	Chung and Pfost (1967)

BET – Brunauer-Emmett-Teller; M_{eq} – equilibrium moisture content (% d.b.); M_0 – initial moisture content of cassava pulp (% d.b.); A, B, C, n – isotherm parameters; RH – relative humidity (fraction); T – drying temperature (°C)

Fig. 1. Weight indicator and cassava pulp (a), glass bottle and salt solution (b), BINDER incubator model BD 53 (BINDER GmbH, Germany) (c), PMB moisture balances (PMB 53; Adam, USA) (d)

LiCl, $MgCl_2$, NaBr, NaCl and KNO_3; each solution was poured to two sealed glass bottles at the volume of 250 cm^3. Then, the wire mesh was put on top of each glass bottle above the saturated salt solution level about 20 mm inside the glass bottle. The cassava pulp samples were placed on the wire mesh (Fig. 1b). The glass bottle with cassava pulp samples were placed in the BINDER incubator model BD 53 (BINDER GmbH, Germany) and with controlled temperature at 30°C (Fig. 1c). After 5 days samples in bottles were weighed placed back to the oven. Afterwards, the samples were weighed every day until the weight was constant and did not change any more (± 0.01 g). Then, the cassava pulp samples were removed from glass bottles and were put in the PMB moisture balances (PMB 53; Adam, USA) to dry at 105°C for 2 h to evaluate the equilibrium moisture content (Fig. 1d). The experimental results were analysed to determine the parameters of the equilibrium moisture content isotherm (Table 1). The above-mentioned procedure was repeated with incubator temperatures of 50 and 70°C.

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RESULTS AND DISCUSSION

The results of the experiment are shown in Table 2. It was found that the equilibrium moisture content of cassava pulp is related to relative humidity and drying temperature as follows: the equilibrium moisture content was increased with increased relative humidity whereas it was decreased with increased drying temperature. The equilibrium moisture content was clearly increased with relative humidity more than 60%. The reason may be that with the increased air temperature and relative humidity, water molecules get activated due to their energy level, causing them to become less stable and to break away from the water-binding site of the food materials, thus decreasing the mono-layer moisture content (Hossain et al. 2001). The negative temperature effect on the equilibrium moisture content was documented in many foods of high-sugar content. The change in sorption properties at high water activities may be due to the increased dissolution of sugars in water with the increase of temperature and relative humidity (endothermic process) (Červenka et al. 2015). Thus, the drying process and storage method of cassava pulp must control temperature and relative humidity of no more than 50°C and 60%, respectively. The relationship of moisture content with relative humidity and drying temperature is shown in Fig. 2.

In addition, the analysis of the determined parameters of various equilibrium moisture content isotherms used a nonlinear regression technique at a computer programme that considers R^2 correlation to indicate the best fit of isotherm equations (higher R^2). The results of nonlinear regression are shown in Table 3 and comparison of the ex-

Table 2. Results of cassava pulp drying with relative humidity and moisture content

Salt saturated	Drying temperature (°C)					
	30		50		70	
	RH	M	RH	M	RH	M
LiCl	0.118	19.059	0.114	18.482	0.110	16.508
$MgCl_2$	0.328	37.284	0.314	30.352	0.267	22.366
NaBr	0.563	69.416	0.511	45.538	0.475	28.951
NaCl	0.756	158.072	0.747	106.217	0.733	65.944
KNO_3	0.907	372.165	0.850	284.434	0.791	189.444

RH – relative humidity (fraction); M – moisture content (% d.b.)

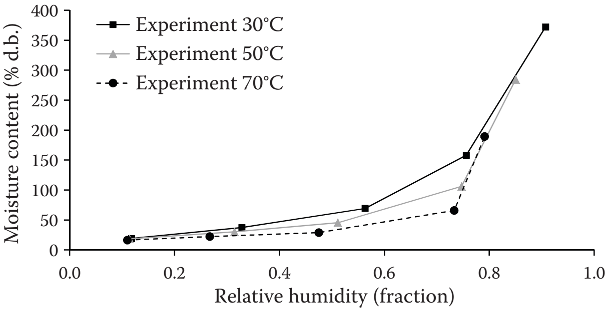

Fig. 2. Relationship of the moisture content with relative humidity and drying temperature

Table 3. Result of nonlinear regression analysis for equilibrium moisture isotherms

Equation	Temperature (°C)	Parameter	R^2
BET	30	M_0 = 35.6 C = 7.416	0.9953
	50	M_0 = 48.86 C = 0.5937	0.9754
	70	M_0 = 5,651 C = 0.0013	0.9184
Oswin	30	A = 63.7 n = 0.7758	0.9986
	50	A = 36.6 n = 1.111	0.9770
	70	A = 14.13 n = 1.692	0.9101
Halsey	30	A = 2,203 B = 1.118	0.9973
	50	A = 598.7 B = 0.7771	0.9841
	70	A = 238.4 B = 0.5458	0.9060
Henderson	30	A = 0.001757 B = 0.644	0.9965
	50	A = 0.002912 B = 0.4649	0.9679
	70	A = 0.005569 B = 0.2837	0.9216
Chung-Pfost	30	A = 0.01498 B = –22.78 C = 15.15	0.9469
	50	A = 0.0215 B = –47.46 C = 5.922	0.9262
	70	A = 0.03727 B = 0.0004187 C = 208	0.8982

BET – Brunauer-Emmett-Teller; M_0 – initial moisture content of cassava pulp (% d.b.); A, B, C, n – isotherm parameters

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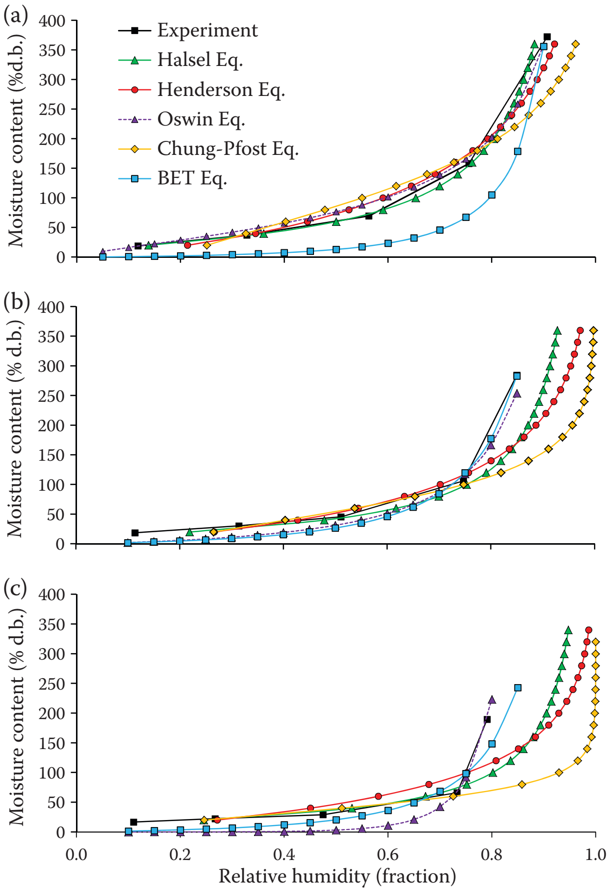

Fig. 3. Experimental and predicted values of five equilibrium moisture isotherms at temperatures of 30°C (a), 50°C (b) and 70°C (c)

BET – Brunauer-Emmett-Teller

periment with five predicted equilibrium moisture content isotherms is shown in Fig. 3.

From the analysis of five isotherm equations results, the equilibrium moisture content was predicted with low accuracy when temperature and relative humidity were higher than 50°C and 0.6 respectively. The model fitted well to the experimental data with relative humidity < 0.60, since the hypothesis of the correct fit cannot be verified above this value. Thus, the equation is not capable to predict the sorption behaviour accurately. Table 3 shows that the correlation R^2 decreased when drying temperature increased(because this experiment used the static method to evaluate the equilibrium moisture content that focuses on the desorption phase rather than the adsorption phase. Hence, when temperature and relative humidity increased, the cassava pulp samples showed higher condensation development during the experimental process (Chong-Ho, Do-Sup 1995). From this result, researchers used their isotherm equations (as shown in Table 3) as a guideline to develop a new equilibrium moisture content isotherm suitable for predicting the equilibrium moisture content of cassava pulp. The sigmoid curve fitting method was used to build a new isotherm equation. The new isotherm equation and parameters with correlation R^2 are shown in Table 4. It was found that the new developed isotherm equation had higher accuracy to predict the equilibrium moisture content with the experiment results compared to the isotherm equations for drying in the temperature range of 30–50°C. However, the accuracy was decreased when drying temperature was higher than 50°C. In this experiment, the correlation R^2 was between 0.9703–0.9999. A comparison of the new isotherm equation with the experimental results is shown in Fig. 4a.

Table 4 shows that the new isotherm parameters A, B, C and D were used in the non-linear regres-

Table 4. New isotherm equation and drying parameters

Equation	Temperature (°C)	Parameter	R^2
	30	A = 0.3509 B = 7.455 C = 63.65 D = 11.2	0.9999
$M_{eq} = A \times \exp(B \times \mathrm{RH}) + (C \times \mathrm{RH}) + D$	50	A = 0.002104 B = 13.44 C = 62.9 D = 11.03	0.9985
	70	A = 0.0000289 B = 18.83 C = 33.36 D = 13.06	0.9703

M_{eq} – equilibrium moisture content (% d.b.), RH – relative humidity

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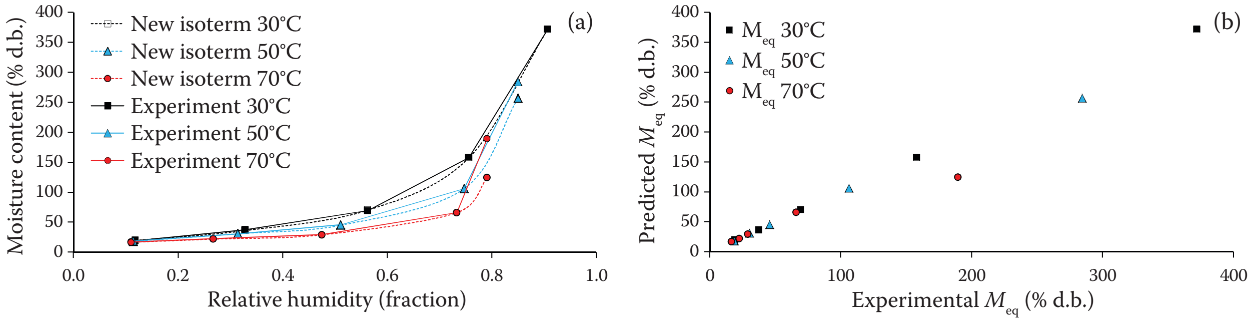

Fig. 4. Comparison of new isotherm equation with experimental results for temperatures of 30, 50 and 70°C (a), experimental versus predicted equilibrium moisture content (M_{eq}) of the new isotherm (b)

sion method to account for the function of drying temperature. The accepted isotherm parameters were as follows (Eq. 1):

$$M_{eq} = A \times \exp(B \times \mathrm{RH}) + (C \times \mathrm{RH}) + D \quad (1)$$

where: M_{eq} – equilibrium moisture content (% d.b.); $A = 1.383 \times 10^{15} T^{-10.56}$; $B = -743.7 \times 10^{-6} T^2 + 0.3587T - 2.638$; RH – relative humidity (fraction); $C = -8.646 \times 10^{-15} T^{8.429} + 64.17$; $D = 250 \times 10^6 T^2 - 0.0285T + 11.83$

The new isotherm equation on the function of drying temperature and relative humidity has average $R^2 = 0.9741$ for drying in the temperature range of 30–70°C. A comparison of predicted equilibrium moisture content from Eq. 1 with the experimental equilibrium moisture content is shown in Fig. 4b. Therefore, the Eq. 1 can be used to predict and define conditions of cassava pulp for safe and long-life storage if air temperature is known, and in the drying process this equation may be used to predict the final moisture content and drying time at any drying temperature to estimate the drying process (Červenka et al. 2015).

CONCLUSION

The study focused on the effect of relative humidity on the equilibrium moisture content of cassava pulp. The results show that the equilibrium moisture content of cassava pulp is related to relative humidity and drying temperature as follows: equilibrium moisture content increased with increased relative humidity whereas it decreased with increased drying temperature. Thus, the drying process and storage methods of cassava pulp must control temperature and relative humidity of no more than 50°C and 60%, respectively. The analysis of five isotherm equations results showed that the equilibrium moisture content was predicted with low accuracy. These results were guideline to develop a new isotherm equation, which enabled to predict the equilibrium moisture content for cassava pulp drying in the temperature range of 30–70°C with higher accuracy than five isotherm equations.

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