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# Moisture Sorption Isotherm Characteristics of Taro Flour

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**Abstract:** It is very important to control moisture content of food during processing and storage since water has many roles in food reactions and food quality. Knowledge of sorption isotherm has a great importance in food dehydration. Taro (*Colocasia esculenta* L. Schott) is one of important sources of carbohydrate in Africa and Asia. The fresh taro, which has high moisture content, can be kept only within a few weeks after harvest. Processing the corms by drying and changing into flour is one solution for easy handling and long-term storage. Moisture sorption isotherm information is clearly needed for processing of taro flour. However, the published literature about the sorption isotherms of taro flour is limited. The objectives of this work were (a) to obtain data on adsorption and desorption isotherms of taro flour at 18, 25 and 35°C; and (b) to evaluate three sorption isotherm models (BET, GAB and DLP models). It was concluded that the sorption isotherms had sigmoid-shape profiles. The hysteresis effects of the sorption isotherms at the three temperatures were distinctly expressed. The Double Log Polynomial (DLP) model was the most appropriate model for the sorption isotherms of taro flour.

**Key words:** Moisture sorption isotherm · Mathematical modeling · Hysteresis · Taro (*Colocasia esculenta* L. Schott)

## INTRODUCTION

Controlling of food moisture content during processing and storage is very important since water has many roles in food reactions and food quality. Al-Muhtaseb [1] stated that the knowledge of sorption isotherm is an extremely important tool in food dehydration, especially to predict the shelf life of dried foods. Modeling for water sorption isotherms has a special interest for many aspects of food preservation, including the thermodynamic functions of the water absorption.

There were many studies on moisture sorption isotherms of foods over the last two decades. Some of these works were related to the determination of moisture sorption isotherms and others were related to the mathematical modeling to represent the moisture sorption isotherms. The Equilibrium Relative Humidity (ERH) and Equilibrium Moisture Content (EMC) of sweet potato slices at five temperatures were investigated by Chen [2]. It was found that the modified Oswin and modified Halsey equations were the adequate models. Using the previously published data, the adequacy of ERH models for high-starch products were evaluated. The Guggenheim-Anderson-de Boer (GAB) model was not adequate and a simplified linear empirical model was developed to describe the sorption data. According to K aymak-Ertekin and Gedik [3], the Halsey, GAB, Oswin and modified Halsey equations are suitable for representing the sorption behaviour of potatoes containing high starch. Their results showed a good agreement with the results of McLaughlin and Magee [4]. Samapundo *et al*. [5] studied the adsorption and desorption isotherms of yellow dent corn at 25, 30 and 37°C. The isotherms showed Type II behaviour and the equilibrium moisture content decreased with increase in temperature. The GAB model was the best fit model for the experimental data. The isosteric heat of sorption was found to decrease with increase in moisture content. Oyelade *et al*. [6] constructed adsorption and desorption (sorption) moisture isotherms for yam flour at the temperature of 27, 32, 37 and 40°C, in the water activity

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($a_w$) range of 0.10–0.80. There were significant effects of temperature on the isotherms which appeared sigmoid. Five widely recommended three parameters sorption models were fitted to the data and desorption isotherms appeared well fitted than adsorption isotherms. The modified Oswin model described the sorption characteristics of yam flour better than other models.

Taro (*Colocasia esculenta* L. Schott) can be considered as one of important sources of carbohydrate for people in Africa and Asia [7, 8]. The fresh corms, which have high moisture content, must be consumed within a few weeks after harvest. It has to be dried to lower moisture content and processed into flour for easy and long-term storage. Therefore, moisture sorption isotherm information is required for drying and storing of taro flour. However, the published literature about the sorption isotherms of taro flour is limited. The objectives of this work were (a) to obtain data on adsorption and desorption isotherms of taro flour at 18, 25 and 35°C; and (b) to compare fittings of three sorption isotherm models (BET, GAB and DLP models).

## MATERIALS AND METHODS

**Taro Flour Preparation:** Fresh taro was purchased from a local farmer in Kaohsiung and kept in an open paper bag at room temperature for 3 days prior to their use. After washing, peeling and slicing, taro was dried using a hot air dryer at 45°C for 12 hours [9]. The dried taro was milled using a lab use grinder to make taro flour. Samples used in the experiment were taro flour 40 mesh. Figure 1 shows the steps in the preparation of taro flour.

Fresh Taro
↓
Washing
↓
Peeling
↓
Slicing
↓
Hot air drying (45°C, 12 hrs)
↓
Milling
↓
Sieving
↓
Taro flour

Fig. 1: The processing steps in preparation of taro flour

**Measurement of Sorption Isotherm [10, 11]:** Moisture Analyzer MX-50 was used to determine the moisture contents of taro flour samples immediately before measuring the sorption isotherms of the taro flour. A sample of 5 g was placed in the sample dish and the temperature was set up at 105°C. Three replications were done for each isotherm temperature. The average values of the moisture contents, which were calculated in % dry basis, were used in analyzing data of the sorption isotherms.

AquaSorp Isotherm Generator (Decagon Devices, Inc., Pullman, Washington, USA) was used to construct moisture sorption isotherms of taro flour at 18, 25 and 35°C. The Aquasorp creates isotherms using a water activity and gravimetric analysis method called Dynamic Dewpoint Isotherm (DDI). Samples used in each temperature were ± 700 mg. The instrument was set up as followed: range of $a_w$ was 0.10-0.85, adsorption minimum, total sorption = 2 (adsorption and desorption) and pump flow rate 300 mL/min. The software for data analysis is SorpTrac$^{TM}$ Version 1.14 for AquaSorp Isotherm Generator.

There were three sorption isotherm models: Brunauer-Emmett-Teller (BET), Guggenheim-Anderson-de Boer (GAB), Double Log Polynomial (DLP) models that were evaluated. The equations of the three models are as follows:

(1) BET equation:

$$m = \frac{a_w m_o c}{(1 - a_w)[1 + a_w(c - 1)]}$$

Where $m$ is the moisture in g/100 solids or g/g solids at water activity $a_w$ and $m_o$ is the monolayer value in the same units. The constant $c$ is calculated by:

$$c = exp\left(\frac{Q_s}{RT}\right)$$

Where $Q_s$ is the surface interaction energy in J/mole, $R$ is the gas constant (8.314 J/mol K) and $T$ (K) is the temperature.

(2) GAB equation:

$$m = \frac{m_o\, k_b\, c\, a_w}{(1 - k_b\, a_w)(1 - k_b\, a_w + k_b\, c\, a_w)}$$

Where $m$ is the moisture in g/100 solids or g/g solids, $k_b$ is a constant in the range of 0.70 to 1 and $c$ is a constant in the range of 1 to 2000. In addition, $m_o$ is the monolayer moisture content in the same units as $m$ and $a_w$ is the water activity at moisture $m$.

(3) DLP equation:

$$m = b_3 \chi^3 + b_2 \chi^2 + b_1 \chi + b_0$$

Where $m$ is the moisture in g/100 solids or g/g solids, $\chi = ln[-ln(a_w)]$ and $b_0 - b_3$ are empirical constants.

The software fitted the generated sorption isotherm data into the three models and calculated the coefficients of equations, standard errors (SE) and coefficient of determinations ($R^2$) for each model at the three temperatures.

## RESULTS AND DISCUSSION

Figures 2, 3 and 4 showed the adsorption and desorption isotherms of taro flour at 18, 25 and 35°C, respectively. The data points for each adsorption and desorption curve were generated by the Aquasorp during the measurement of sorption isotherms. The moisture contents of taro flour, in % dry basis, measured before isotherm testing were 7.86±0.11, 6.00±0.13 and 5.67±0.03% for 18, 25 and 35°C, respectively. The moisture sorption isotherms had sigmoid-shape profiles for all of the three temperatures which were similar with yam flour [6]. The hysteresis effects at the three temperatures were distinctly expressed. The increasing temperatures resulted in the less hysteresis effect on taro flour which meant the adsorption and desorption curves were closer.

Table 1 listed the results of the coefficients of equations, standard errors (SE) and coefficient of determinations ($R^2$) for BET, GAB and DLP models of taro flour at 18, 25 and 35°C. The three models had low SE values (less than or close to 0.50) and high $R^2$ values (higher than 0.9). Thus, it can be concluded that the three models were well fitted for the sorption isotherms of taro flour. However, SE values of the GAB model were higher than the other two models. It should also be noted that the BET equation is generally applicable up to $a_w$ value of 0.45-0.50 [10]. Therefore, the DLP model could be considered as the most appropriate model for the moisture sorption isotherms of taro flour.

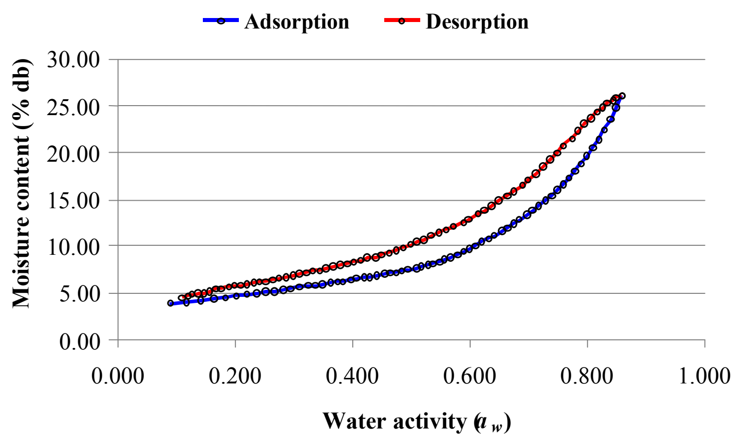


Fig. 2: Sorption isotherm of taro flour at 18°C

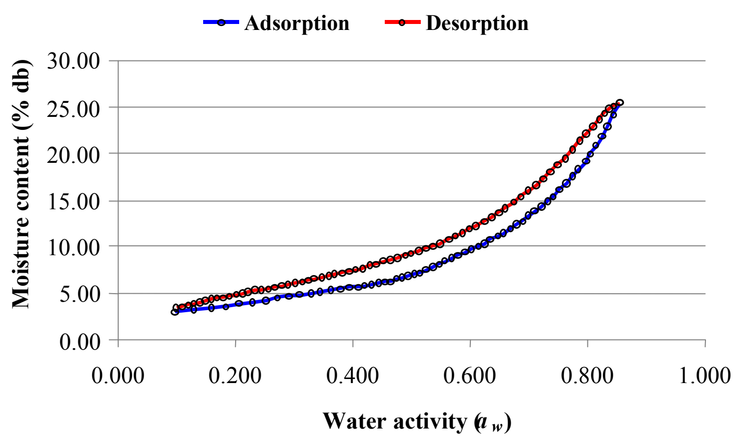


Fig. 3: Sorption isotherm of taro flour at 25°C

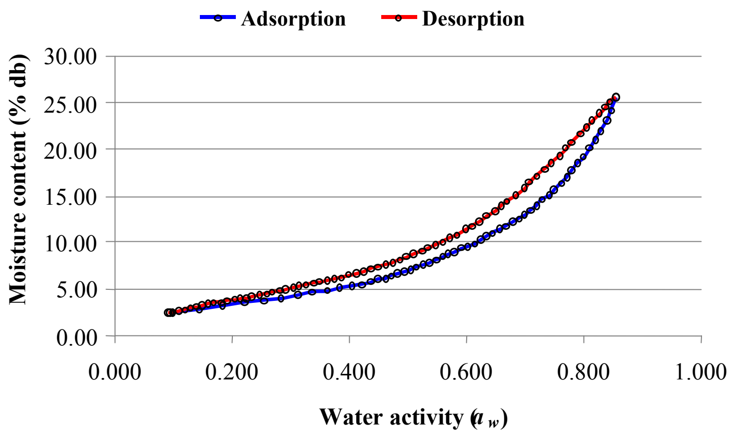


Fig. 4: Sorption isotherm of taro flour at 35°C

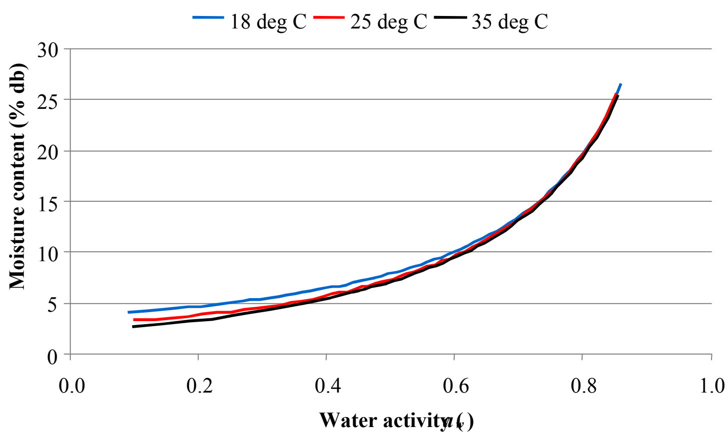


Fig. 5: Adsorption isotherms of taro flour based on DLP model at 18, 25 and 35°C

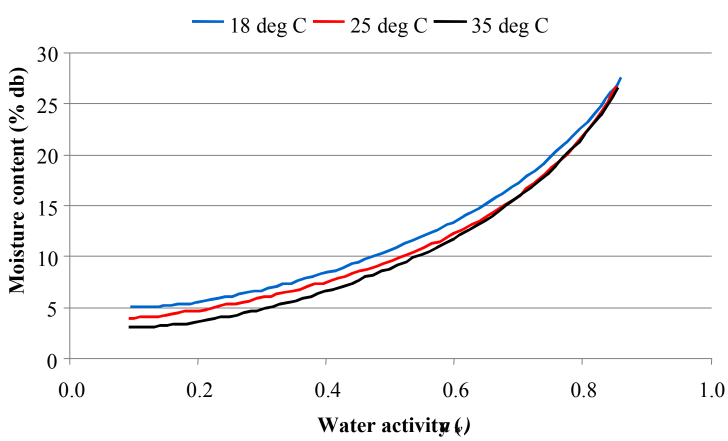


Fig. 6: Desorption isotherms of taro flour based on DLP model at 18, 25 and 35°C

Figure 5 and 6 showed the adsorption and desorption isotherm curves of taro flour based on DLP model, respectively. In general, the moisture content decreased with increase in temperature which agreed with the results of Samapundo *et al.* [5] and Oyelade *et al.* [6]. For the adsorption isotherms (Figure 5), the curves closed each other as water activity increased especially at $a_w$ value higher than 0.60. While the desorption isotherms in figure 6 showed that the 18°C curve was separated from the other two curves.

Table 1: Coefficients, standard errors (SE) and coefficient of determinations ($R^2$) of the sorption isotherm models for taro flour

| | | Adsorption | | | Desorption | | |
|---|---|---|---|---|---|---|---|
| Temp | Model | Coefficients | SE | $R^2$ | Coefficients | SE | $R^2$ |
| 18°C | BET | $c$: 85.9989 | 0.05 | 0.996 | $c$: 27.4508 | 0.04 | 0.999 |
| | | $m_o$: 3.9281 | | | $m_o$: 5.2519 | | |
| | GAB | $c$: 34.0454 | 0.25 | 0.998 | $c$: 11.4165 | 0.53 | 0.994 |
| | | $k_b$: 0.9832 | | | $k_b$: 0.9012 | | |
| | | $m_o$: 4.1602 | | | $m_o$: 6.4713 | | |
| | DLP | $b_0$: 6.0048 | 0.16 | 0.999 | $b_0$: 7.7315 | 0.37 | 0.997 |
| | | $b_1$: -3.8918 | | | $b_1$: -6.4264 | | |
| | | $b_2$: 2.4653 | | | $b_2$: 3.1883 | | |
| | | $b_3$: -0.6252 | | | $b_3$: 0.5740 | | |
| 25°C | BET | $c$: 26.0463 | 0.03 | 0.998 | $c$: 15.0891 | | |
| | | $m_o$: 3.5764 | | | $m_o$: 4.9338 | 0.03 | 0.999 |
| | GAB | $c$: 8.7201 | 0.32 | 0.997 | $c$: 8.6190 | 0.38 | 0.996 |
| | | $k_b$: 0.9845 | | | $k_b$: 0.9238 | | |
| | | $m_o$: 4.2286 | | | $m_o$: 5.8703 | | |
| | DLP | $b_0$: 5.2221 | 0.14 | 0.999 | $b_0$: 6.9193 | 0.28 | 0.998 |
| | | $b_1$: - 4.3796 | | | $b_1$: -6.0328 | | |
| | | $b_2$: 2.8224 | | | $b_2$: 2.7062 | | |
| | | $b_3$ = - 0.4017 | | | $b_3$: 0.1056 | | |
| 35°C | BET | $c$: 11.8095 | 0.08 | 0.990 | $c$: 7.8585 | 0.05 | 0.998 |
| | | $m_o$: 3.6620 | | | $m_o$: 4.7046 | | |
| | GAB | $c$: 5.5562 | 0.25 | 0.998 | $c$: 4.1109 | 0.48 | 0.995 |
| | | $k_b$: 0.9752 | | | $k_b$: 0.9167 | | |
| | | $m_o$: 4.4196 | | | $m_o$: 6.2517 | | |
| | DLP | $b_0$: 4.9742 | 0.09 | 1.000 | $b_0$: 5.9699 | 0.31 | 0.998 |
| | | $b_1$: - 4.7227 | | | $b_1$: -6.6232 | | |
| | | $b_2$: 2.6386 | | | $b_2$: 3.2943 | | |
| | | $b_3$: - 0.3789 | | | $b_3$: 0.4896 | | |

Tabel 2: Predicted moisture content values ($m$) of taro flour using DLP model at different water activities ($a_w$)

| | Temperature | | | | | |
|---|---|---|---|---|---|---|
| | 18°C | | 25°C | | 35°C | |
| $a_w$ | $m_{adsorption}$ (% db) | $m_{desorption}$ (% db) | $m_{adsorption}$ (% db) | $m_{desorption}$ (% db) | $m_{adsorption}$ (% db) | $m_{desorption}$ (% db) |
| 0.10 | 4.11 | 4.92 | 3.30 | 3.83 | 2.65 | 3.02 |
| 0.60 | 9.92 | 13.31 | 9.56 | 12.16 | 9.45 | 11.76 |
| 0.80 | 19.50 | 22.61 | 19.50 | 21.70 | 19.27 | 21.66 |
| 0.85 | 24.97 | 26.49 | 24.91 | 26.18 | 24.54 | 25.94 |

The values of the predicted moisture contents of taro flour at four values of water activities were listed in Table 2. The best model, the DLP equation, was used to calculate the moisture contents of adsorption and desorption at the three temperatures. Most foods can not support growth of microorganisms at $a_w$ less than 0.60 and mold growth at $a_w$ equal to 0.80 [10].

It was concluded that the moisture sorption isotherms of taro flour at 18, 25 and 35°C had sigmoid-shape profiles. The hysteresis effects of the sorption isotherms at the three temperatures were distinctly expressed. The Double Log Polynomial (DLP) model was the most appropriate model for the sorption isotherms of taro flour. The increasing temperature in adsorption and desorption isotherms showed decreasing in moisture content at a given water activity

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