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Equilibrium Moisture Contents and Sorption Isotherms of *Amorphophallus konjac* Tuber Slices

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Abstract

Amorphophallus konjac fresh tubers are often used as a raw material for making food because it has a fairly high nutritional content. Therefore, it is very important to measure the equilibrium moisture content of fresh and processed tuber. The present study aimed to determine the best model to represent the equilibrium moisture content for adsorption and desorption isotherms of *Amorphophallus konjac* tuber slices. The tuber samples were sliced into slices (3.0 × 3.0 × 0.8 cm) and rinsed in a 0.2% salt solution for approximately 2 min. Half of the samples were blanched in water bath at 80°C for 5 min. The samples (blanched (B) and non-blanched (NB)) were placed into 6 desiccators containing salt solution with relative humidity of 17%–82%. The desiccators were stored at constant temperatures of 30°C (room temperature) and 40°C. Three models were comparatively evaluated in this study: the Henderson, Oswin, and Chung–Pfost. Excel Solver was applied to determine the value of each parameters in the models. The water sorption isotherms type was sigmoidal, indicating the closed relationship between the single layer area of relative humidity samples with the equilibrium moisture content. Based on the magnitudes of coefficient of determination (R^2), root mean squared error (RMSE), and Chi-square (χ^2) value the Oswin and Chung–Pfost models were found to be the best-fitted models to represent the equilibrium moisture content of *A. konjac* tuber slices at storage temperatures of 30°C and 40°C, respectively.

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1. Introduction

Amorphophallus konjac—is the konjac tuber genus—a tuber plant belonging to the *Araceae* family (1) (Figure 1) is mostly found in tropical countries in Asia and Africa (2). Commonly, this plant is also known as the voodoo lily (African root), elephant foot taro (India), and konnyaku (China) (3). The konjac tuber has been known for centuries and used as an herbal medicine as well as in traditional foods, such as konjac jelly, tofu, and noodles (4).

A. konjac tuber has high glucomannan content and has been used as a raw material for the production of food product, which includes functional food and beverages (5). This tuber can also be used as a food ingredient with nutritional contents such as starch, protein, fiber, lipid, and glucomannan, as well as anti-nutrition contents in the form of oxalate crystals (6). To reduce calcium oxalate content in konjac tuber, physical methods such as blanching treatment can be used (7). For direct consumption, the tubers are converted into dried chips (8).

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Blanching treatment is an important preparation method for *A. konjac* before drying and storage. The processing of tuber into dried chips is started with blanching for the inactivation of polyphenol oxidase by heating up to 100^{o}C for a certain period to provide a uniform treatment (9).

Figure 1. A representative picture of *Amorphophallus oncophyllus.*

A. konjac fresh tubers were processed into different forms for use as food ingredients, such as dried tuber chips and starch. For these products, an equilibrium moisture content is of paramount importance as it reflects the optimal storage condition. An equilibrium moisture content can be used to describe the sorption isotherm properties (10). However, the present data on sorption isotherm properties of konjac is inadequate. In general, the sorption isotherm properties are affected by temperature and relative humidity (11). The sorption isotherms is extremely important in foods as it can be used to assess food stability and quality during the storage period (12). Past studies on sorption isotherm properties are important as it can provide information on the storage stability of agricultural products (11).

Recent studies on the sorption isotherms of foods from tubers have been reported previously, which includes the sorption isotherms of cassava roots (13), yam chips (14), and potato slices (10).

Sorption isotherms are commonly presented in the form of curves reflecting the relation between relative humidity and equilibrium moisture content of food materials (15,16). The sigmoıdal shape of the sorption isotherms is common for several hygroscopic products and corresponds to type II of the Brunauer’s classification (17).

The present objective was to determine the best model to represent the equilibrium moisture content of *Amorpophalus onchophyllus* tuber slices at 30°C and 40°C under different levels of relative humidity.

2. Materials and Methods

2.1. Material preparation

A. konjac tubers used in this research were obtained from a commercial farmer at the Pangkep Regency, South Sulawesi Province, Indonesia. The samples were stored at room temperature prior to the experiments. This research was conducted at the Food and Agricultural Processing Engineering Laboratory, Hasanuddin University, during August–December 2021. The average weight of the tuber used in study was 900 g. The skin of the tubers was removed before slicing them into small pieces (3.0 × 3.0 × 0.8 cm). Then, 400 g of the slices were rinsed with 0.2% salt solution for 2 min. Half of the samples were then blanched (B) in a hot water bath at 80°C for 5 min to inactivate the enzymes that catalyzes the browning reaction (18). The remaining half of the sample were prepared as a nonblanched (NB) sample (control).

The salts used in this study were saturated with NaOH, $MgCl_2$, K_2CO_3, $NaNO_2$, NaCl, and KCL by dissolving in distilled water until reaching saturation. About 500 mL of the saturated salt solutions were placed in separated desiccators. A total of 12 desiccators were used, six samples were stored in a temperature-controlled wooden box (maintained at 40°C), while the other six samples were kept in a room of temperature 29°C–30°C. The actual relative humidity values of these salt solutions in the respective container were measured with a digital hygrometer (Table 1). A total of four samples were placed in each desiccator; two for adsorption experiment (B and NB dried samples) and the remaining two for desorption (B and NB wet samples).

Table 1. Relative humidity and water activity values of the saturated salt solutions used in the sorption experiment.

Salt solutions	Relative humidity (%RH)	Water activity (a_w)
Sodium hydroxide (NaOH)	17	0.17
Magnesium chloride ($MgCl_2$)	32	0.32
Potassium carbonate (K_2CO_3)	37	0.37
Sodium nitrite ($NaNO_2$)	54	0.54
Sodium chloride (NaCl)	76	0.76
Potassium chloride (KCl)	82	0.82

2.2. Samples preparation for adsorption isotherm

For the adsorption isotherm measurement, the samples (B and NB) were first dried in an oven at **a** constant temperature of 55°C for approximately 38 h until the moisture content was approximately 8% (on a wet-weight basis). Then, 9 g (5 slices) of the dried chips were placed in a container and then in a desiccator. A total of 12 samples were prepared for the adsorption experiment sample containers (B and NB samples). Since six containers were maintained for each temperature condition, the number of sample containers used for the adsorption observation was 12 in total.

2.3. Sample preparation for desorption isotherm

As mentioned earlier, approximately 400 g of the sample slices were rinsed with 0.2% salt solution for approximately 2 min, and half of them were B in a hot water bath at 80°C, while the other 200 g were not left unblanched. Immediately, after this sequential process, about 30 g of these samples were set aside, placed into a sample container, and loaded into the desiccator. The same experiment was repeated with the adsorption observation, and six containers were used for each temperature observation.

2.4. Moisture adsorption and desorption determination

Every 14 days, each sample container was weighed with a digital balance of an accuracy level 0.1 mg. Equilibrium was acknowledged when three consecutive weight measurements of the samples showed a difference of <1.0 mg. It took nearly 10 weeks to reach this equilibrium stage. The equilibrium moisture content (EMC) of the chips was then determined gravimetrically by using the oven drying method (105°C for 72 h) described elsewhere (19). The experiments were replicated twice for a more accurate measurement. The average values of the two replications were used to determine the EMC values of individual treatment combination.

To establish the moisture sorption isotherms, the EMCs were expressed on a dry basis using the following equation:

$$\text{EMC (bk)}=\frac{\text{final weight (a)} - \text{dryweigt (b)}}{\text{dryweight (b)}}\times 100\% \tag{1}$$

Where "a" is the final weight achieved after about 10 weeks of observations and "b" is the oven dry weight.

2.5. Mathematical modeling of adsorption and desorption isotherms

Three models were evaluated in this study, as illustrated in Table 2. These models were relatively simple and easy to operate, and contained only two parameters under a wide range of water activity values (20). For the water-sorption isotherms model, the final dry basis of the moisture contents served as the EMC of the samples. The experimental data were regressed to the three mathematical models using the Microsoft Excel Solver. The Solver function is ideally suited for fitting data with non-linear functions through an iterative algorithm (15).

Table 2. Isotherm equations.

Model	Mathematical equation	
Henderson (1952)	$\text{EMC}= A[-\ln(1-aw)]^{1/B}$	(2)
Oswin (1946)	$EMC = A(\frac{aw}{1-aw})^{B}$	(3)
Chung–Pfost (1976)	$\text{EMC}= A+B\ln(-\ln aw)$	(4)

Where, EMC represents the equilibrium moisture content (decimal d.b.) and a_w is the water activity. A and B are constants (dimensionless parameters).

The accuracy of the model was determined based on the magnitudes of R^2 (the coefficient of determination), RMSE (Root Mean Square Error), and Chi-square (χ^2) values. The R^2 was calculated using the RSQ function of the Microsoft Excel, while the RMSE values of each model were estimated using the following equation:

$$\text{RMSE}=\sqrt{(1/N)\sum_{1}^{N}(\text{EMC}_{\text{obs}}\text{-EMC}_{\text{pred}})^2} \tag{5}$$

$$X^2=\frac{\sum_1^N(\text{EMC}_{\text{obs}}\text{-EMC}_{\text{pred}})^2}{\text{N-n}} \tag{6}$$

Where, EMC_{obs} is the experimental EMC value; EMC_{pred} is the predicted EMC value; N is the number of experimental observations; and n is the number of parameters involved in the model.

The best-fitted model produces RMSE and Chi-square (χ^2) values close to zero (22), and R^2 value close to 1 indicates that the predicted data and the observed data have a good correlation.

3. Results and Discussion

3.1. Sorption isotherm characteristics of A. oncophylus

The sorption isotherm curves of *A. konjac* slices at different treatment (B and NB) and temperature (30°C and 40°C) are shown in Figure 1. Data generated from the desorption experiment for the NB samples at a relative humidity of 82% and temperature of 40°C was removed from the analysis as it was unreasonable. The corresponding sample was probably accidentally contaminated by the salt solution during the experiment.

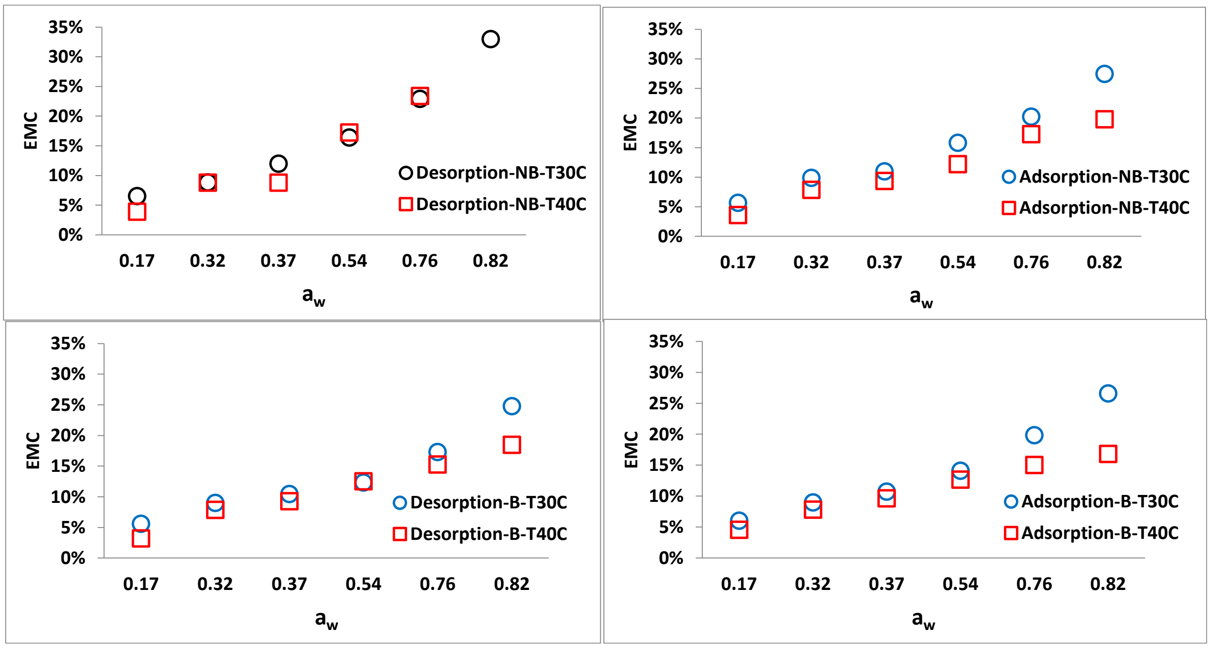

Figure 2. EMC adsorption and desorption of *Amorphophallus oncophylus* nonblanched (NB) and blanched (B) at constant temperatures of 30°C and 40°C.

An increase in the EMC curve was observed, as seen in Figure 1, following a slightly sigmoidal shape curve typical of adsorption and desorption for most food items (22).

Table 1 also shows that EMCs at 40°C had lower value than those at 30°C. This is a common phenomenon for most food materials, where the EMC values decreased with an increase in the temperature at a constant water activity. This could probably be because, with an increase in the temperature, the water molecules get activated due to an increase in their energy level, which causes them to become less stable and to break away from the water-binding site of the food materials, thereby decreasing the monolayer water content (14).

Moreover, most of the time, EMCs of the B samples were smaller than those of the NB ones. At a higher relative humidity value, the difference between the EMC values of the two types of samples was even more consistent. A similar phenomenon was reported by some researchers (15) and (23). The samples that had been previously exposed to hot water blanching at a temperature around their gelatinization point, that is 80°C, might have distracted the ability of the samples to absorb or desorb water from their surroundings.

The present results were consistent with those of previous studies showing that the adsorption process produces lower EMC values than those generated from the desorption process. One reason for the differences in the EMC between desorption and adsorption at a constant temperature and water activity is that, during the desorption, solutes may supersaturate below their crystallization water activity and, therefore, can hold more water (14).

3.2. Moisture sorption isotherm modeling for A. oncophylus slices

As mentioned earlier, 3 models were evaluated in this study, namely the Henderson, Oswin, and the Chung–Pfost models. The results of the curve-fitting analysis using the Microsoft Excel Solver are presented in Table 3.

Table 3. Constants involved in the models with the values of R^2, χ^2, and RMSE.

Treatment		**Model**	**Parameter**		**R_2**	**RMSE**	**X_2**
			A	**B**			
Adsorption Non-Blanching	30°C	Henderson	0.18004756	0.66060422	0.96789288	0.01293745	0.00025107
		Oswin	0.13480193	0.44138064	**0.9710677**	0.01228969	0.00022655
		Chung-Pfost	0.10922608	-0.091085	0.9692235	0.01266515	0.00024061
	40°C	Henderson	0.1402176	0.63759793	0.98793874	0.00613577	5.6472E-05
		Oswin	0.10613056	0.42323719	0.97364934	0.0090632	0.00012321
		Chung-Pfost	0.08516601	-0.0702698	**0.99071966**	0.00530691	4.2245E-05
Adsorption Blanching	30°C	Henderson	0.17223956	0.67846219	0.97181617	0.0117433	0.00020686
		Oswin	0.12804793	0.45325112	**0.98273925**	0.00915265	0.00012566
		Chung-Pfost	0.10429499	-0.0879074	0.97033376	0.01199395	0.00021578
	40°C	Henderson	0.13036899	0.49535585	**0.96751908**	0.00767258	8.8303E-05
		Oswin	0.10474425	0.33070351	0.94036171	0.01037898	0.00016158
		Chung-Pfost	0.08715515	-0.0528784	0.9578995	0.00865024	0.00011224
Desorption Non-Blanching	30°C	Henderson	0.19975225	0.77498446	0.95692966	0.01889711	0.00053565
		Oswin	0.14282689	0.51422866	**0.9698866**	0.01573704	0.00037148
		Chung-Pfost	0.11510968	-0.1131253	0.94953776	0.02034946	0.00062115
	40°C	Henderson	0.18293336	0.78788233	0.96750284	0.01163037	0.0002029
		Oswin	0.1310854	0.53793265	0.94528872	0.0151168	0.00034278
		Chung-Pfost	0.1009154	-0.1084285	**0.9752477**	0.01001621	0.00015049
Desorption Blanching	30°C	Henderson	0.15808689	0.65051239	0.93879943	0.01551865	0.00036124
		Oswin	0.1186622	0.43843936	**0.95721325**	0.01294923	0.00025152
		Chung-Pfost	0.16756008	0.07622202	0.87575895	0.02203949	0.00072861
	40°C	Henderson	0.1326867	0.587192	0.95893977	0.01023831	0.00015723
		Oswin	0.10247414	0.39120768	0.93713418	0.01264697	0.00023992
		Chung-Pfost	0.08280536	-0.0627292	**0.95957108**	0.01004716	0.00015142

Table 3 strongly indicates that the Oswin equation is the most appropriate model to represent the behavior of EMC of the B and NB samples for both adsorption and desorption experiments, specifically at a storage temperature of 30°C. Its R^2 values ranged from 0.96 to 0.98 along with extremely small values of RMSE and Chi-square X^2. On the other hand, the Chung–Pfost equation performs much better, the R^2 values ranging from 0.96 to 0.99, at storage temperature of 40°C for non-blanching adsorption experiment and for both blanching and non-blanching desorption experiments. Henderson equation performed well, with R^2 value of 0.97, only for the B sample stored at a temperature of 40°C in the adsorption experiment. The R^2 value of the Chung–Pfost equation for the latter combination treatment was only slightly smaller than that of the Henderson equation (0.96). With such phenomenon, it is relatively safe to assume that the Chung–Pfost equation was sufficiently suitable to predict the behavior of the EMC of the B and NB samples for both the adsorption and desorption experiments at a temperature of 40°C.

Oswin and Chung–Pfost EMC predicted the values, and the observed EMC values are depicted in Figure 3. This figure strongly indicates that the predicted and observed EMC values are extremely close.

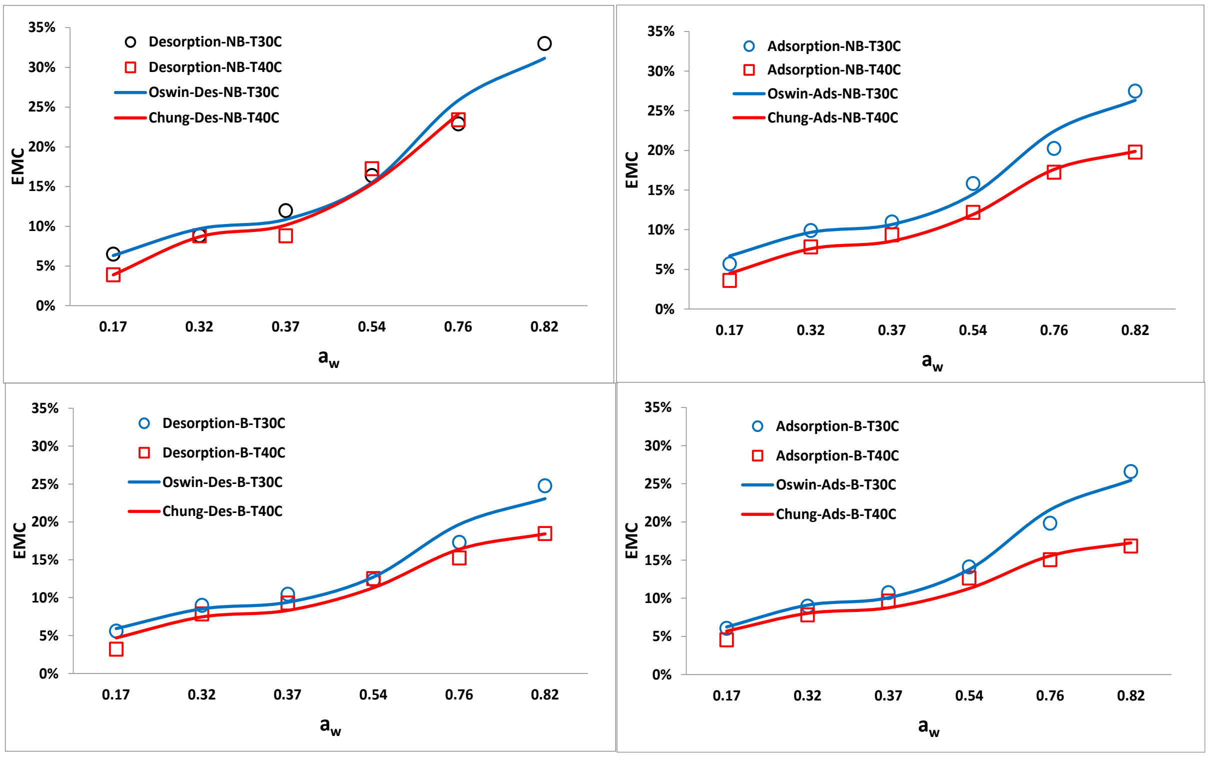

Figure 3. EMC values vs. Oswin and Chung–Pfost predicted values.

4. Conclusions

The Oswin equation is the most appropriate model to represent the behavior of EMC of the B and NB *A. konjac* tuber slices for both the adsorption and desorption experiments, specifically at a storage temperature of 30°C. The Chung–Pfost equation, on the other hand, is sufficiently suitable to predict the behavior of the EMC of the B and NB samples for both the adsorption and desorption experiments at a temperature of 40°C. Moreover, an increase in the storage temperature gives smaller values of EMC. Furthermore, B *A. konjac* possessed lower EMC values when compared to the NB one.

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Author Contributions

S.R., J.M. and S. conceived and designed the experiments; S.R. and A.L. performed the experiments; S.R. and S. analyzed the data; J.M., S. and A.L. contributed reagents/materials/analysis tools; S.R. and S. wrote the paper.

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Conflicts of Interest

The authors declare no conflict of interest.

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