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Sorption characteristics of banana slices (*Musa paradisiaca* L.) var. Raja Nangka by gravity method

La Choviya Hawa*, Anang Lastrianto, Tanti Nirwana Tambunan

Department of Agricultural Engineering, Faculty of Agricultural Technology, Universitas Brawijaya, Jl. Veteran, Malang, Indonesia

KEYWORDS

Drying
GAB model
Moisture sorption isotherm
Raja Nangka banana

ABSTRACT

Banana Raja Nangka (*Musa paradisiaca L.*) is a type of banana having a low economic value compared to other bananas due to its slight sour taste. Alternative valorisation of the banana is to make is into banana flour. Drying of banana slices var. Raja Nangka is an important factor to produce good quality of banana flour product. Drying is influenced by water content, water activity (a_w), relative humidity (RH), moisture content balance, temperature, type of drying, drying rate, etc. The thermodynamic relationship between a_w and moisture content balance of food products at constant temperature and pressure can be described by the behavior of moisture sorption isotherm. This research used a static gravimetric method composed of two treatment include desorption and adsorption samples at five levels of a_w conditioned by using 5 g saturated salts: KOH (0.0738), $MgCl_2$ (0.3244), $CaCl_2$ (0.6183), NaCl (0.7509), KCl (0.8362) and three levels of temperature (i.e. 30, 40, and 50°C) in triplicate. Analysis of moisture sorption isotherm was carried out by weighing the samples on a daily basis until moisture content balance is reached. Moisture content balance is then fitted by using Wgnuplot software and the curve display is plotted by SM4WIN software. The results of moisture sorption isotherm indicated that moisture content balance can be obtained within 10 days. The curve of water desorption and adsorption and the curve of hysteresis were well fitted in type II, known as sigmoid type. In the desorption sample, Xm was obtained at 30, 40 and 50°C with the values of 0.148, 0.096, 0.055 (kg water/kg solid) and the adsorption samples were 0.12, 0.059, 0.54 (kg water/kg solid), respectively. The C value of C in desorption sample was 66.18, 34.15, 23.70, while in adsorption samples were 67.88, 21.87, 75.53. The K values in desorption samples were 0.81, 0.86, 0.90 and in adsorption samples were 0.72, 0.89, 0.87.

Introduction

The thermodynamic relationship between water activity (a_w) and moisture content balance of food products at constant temperature and pressure is called moisture sorption isotherm. Moisture sorption isotherm is critical to determine the packaging design and the optimum drying time, storage, prediction of the quality stability, shelf-life, and calculation of moisture changes that may occur during storage (Ricardo et al., 2011). Various equations models of moisture sorption isotherm for banana were developed to illustrate the moisture content balance. Falade and Awoyele (2005) used eight models include BET, GAB, Oswin, Hasley, Henderson, Chung-Pfost, Chen and Smith. While, Aguirre-Cruz et al. (2010) used BET, GAB, Smith, and Iglesias-Chirife. They reported that GAB model was best to explain the moisture content characteristics of banana.

This research aimed to investigate the behavior of moisture sorption isotherm of banana slices var. Raja Nangka (*Musa paradisiaca* L.) stored in an incubator at temperatures of 30, 40, and 50°C, and at a_w in the range of 0.06-0.84. Also to determine the characteristics of moisture sorption isotherm curves from banana slices var. Raja Nangka using the GAB model (Guggenheim-Anderson-de Boer). The characteristic curve was deployed from the experimental data.

Research Methods

This research was carried out at the Laboratory of Food and Agricultural Processing Engineering, Department of Agricultural Engineering and Laboratory of Food Quality

* Corresponding author
E-mail address: la_choviya@ub.ac.id

and Safety Testing, Department of Agricultural Technology, Faculty of Agricultural Technology Universitas Brawijaya.

Banana var. Raja Nangka (*Musa paradisiaca* L.) was used in this study and purchased from Merjosari market, Malang. The saturated salts (i.e. KOH, $MgCl_2$, $CaCl_2$, NaCl and KCl) and 80% ethanol pro-analyst were obtained from CV. Kimia Makmur Sejati, Malang, and distilled water from Hydrobatt brand.

Experimental procedures

Two types of treatments include desorption and adsorption samples treated with five different types of a_w saturated salts, such as (KOH (0.0738), $MgCl_2$ (0.3244), $CaCl_2$ (0.6183), NaCl (0.7509), and KCl (0.8362)) and with three different temperatures of 30, 40, and 50ºC. all experiments were carried out in triplicate.

The saturated salt solution was preapred by dissolving saturated salts of KOH, $MgCl_2$, $CaCl_2$, NaCl, and KCl, each with a ratio of 1: 0.2 w/v distilled water at room temperature of approximately 27°C. The solutions were allowed to stand for 72 hours until the formation of crystal precipitates were evident. The a_w value of each saturated salt is listed in Table 1.

Table 1. The Value of a_w in different types of saturated salt

	Water Activity (a_w)		
	30 ºC	**40 ºC**	**50 ºC**
KOH	0.0738 ±0.56	0.0626 ±0.35	0.0572 ± 0.27
$MgCl_2$	0.3244 ±0.14	0.3160 ±0.13	0.3054 ± 0.14
$CaCl_2$	0.6183 ±2.80	0.5548 ±1.80	0.5001 ± 1.40
NaCl	0.7509 ±0.11	0.7468 ±0.13	0.7443 ± 0.19
KCl	0.8362 ±0.25	0.8232 ±0.25	0.8120 ± 0.31

Preparation of the banana slices samples include following steps. First, banana var. Raja Nangka was peeled and cleaned with water. The clean banana was sliced using a slicer with a thickness of ~1 mm. Then, weighed for 1 g and placed in a sterilised aluminum foil dish.

For desorption samples, fresh banana slices was used with a thickness of ~1 mm and weight of 1 g, aiming to investigate the water evaporation when stored in the incubator. For adsorption samples, banana slices were dried with a thickness of ~1 mm and weight of 1 g using a tray dryer LCH-0115 at temperature of 50 ºC for 450 minutes, assuming that the sample weight was expected to be less than 2% (Hawa et al., 2014a, 2014b). Aftre drying, the samples were then placed in a desiccator containing silica gel at room temperature of ~27 °C for 2 days. Next, the banana samples were placed in airtight plastic container containing saturated salt solution with a known a_w value. Then, the container was stored in an incubator under the temperature of 30, 40, and 50 ºC. The samples were weighted on a daily basis. The weighing process was stopped when a decrease in sample weight was less than 2% or the sample weight is stable for 3 days or when there was an increase weight in the desorption samples and a decrease weight on the adsorption samples. Such behaviour indicated that the moisture content of the samples were in balance with the environment. Next, the samples were placed in an oven at 105 °C for 4 hours to determine the weight of dry solids. Determination of moisture content is calculated by the gravimetric method, as follows:

$$WC = \frac{(W\,solid + water - W\,solid\,)}{Wsolid} \qquad [1]$$

The GAB model used:

$$X = \frac{C\,K\,X_m\,a_w}{(1 - Ka_w)(1 - Ka_w + CKa_w)} \qquad [2]$$

Parameters for error value were used to evaluate the experimental data obtained with the prediction data using the GAB model. The parameters of error value used in this research include standard deviation, coefficient of determination (R^2) and root mean square error (RMSE).

The standard deviation was calculated using the following equation (Villa-Velez et al., 2012):

$$S = \sqrt{\frac{\sum(x_i - \bar{x})^2}{n}} \quad [3]$$

The R^2 was calculated using equation 4, sa follows (Kwangolo, 2013):

$$R^2 = (\frac{ei - e\ ave}{RMSE})^2 \quad [4]$$

The calculation of RMSE was based on the equation below (Moreira et al., 2008):

$$RMSE = \sqrt{\frac{\sum_{i=1}^{n}(x_i - x_{pred})^2}{n}} \quad [5]$$

Results and Discussion

Moisture sorption isotherm

Moisture sorption curve of desorption and adsorption banana slices var. Raja Nangka are shown in Fig. 1 and 2. Equilibrium moisture content increases with increasing a_w both in desorption and adsorption samples. Moisture sorption isotherm curve of banana is classified as type II (Sigmoid or S letter). According to Labuza (1984), type II curves are commonly found in food products due to the accumulative effect of hydrogen bonds, Raoult's Law, capillaries and the interaction between the material surface with the water molecule, which have two curves, the first curve shaped at a_w around 0.2 - 0.4 and the second curve shaped at a_w around 0.7 - 0.8. Such behaviour was due to changes in physicochemical properties of water binding by the material.

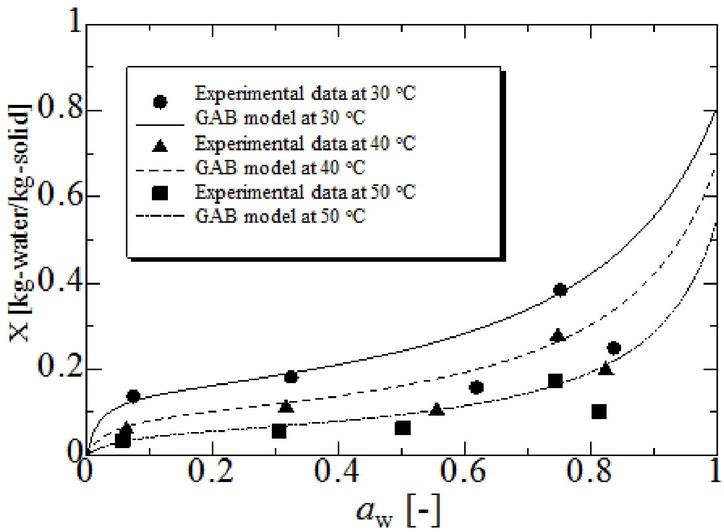

Figure 1. Moisture sorption isotherm curve for desorption banana slices var. Raja Nangka

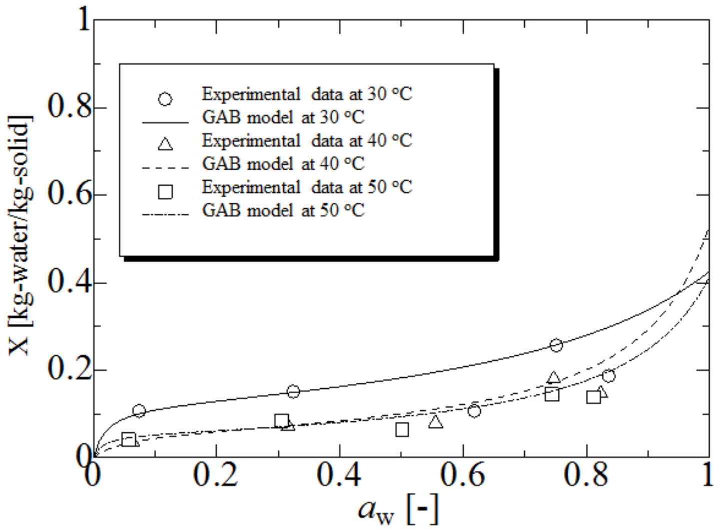

Figure 2. Moisture sorption isotherm curve for adsorption banana slices var. Raja Nangka

The hysteresis curve of banana slices var. Raja Nangka is shown in Fig. 3. The sorption isotherm curve for desorption samples was higher than that of the adsorption samples at temperature of 30, 40 and 50°C. This was possibly due to drying process, particularly the adsorption samples, reducing the moisture content to almost 0. Thus, the drying process on the adsorption samples lead to a reduction or a closure in the pore of banana slices var. Raja Nangka caused by a decrease in the moisture content. Analysis of Variance (ANOVA) testing using the General Linear Model produced P-Value > 0.05, indicated that both adsorption and desorption samples were not significantly different.

Moisture sorption isotherm behavior is described by the GAB model approach. The selection of GAB models was due to several advantages, include: (1) the model can be used in almost all food materials; (2) it has a theoretical background of the improvement from BET theory (Brauner-Emmet-Teller); (3) it can describe the sorption pattern on most of food material with a_w values in the range of 0 - 0.983; (4) it has a simple mathematical form composed of three parameters such as Xm (water content of monolayer), and C, (associated with heat or adsorption energy of monolayer), and K (water binding on the multilayer part with free water); and (5) The parameters have a physical meaning relevant to the sorption process (Chen and Jayas, 1998). The GAB model and error values, as indicated R^2 and RMSE, can be seen in Table 2.

Table 2 shows the value (Xm) of the monolayer water content in both desorption adsorption sample decreases with increasing temperature at constant a_w. This was due to an increase in temperature causes an increase in vapor pressure to evaporate the water content, which leads to lowering the water content of the materials (Kouhila et al., 2006). The difference in the Xm value of the desorption and adsorption samples at temperature of 30, 40 ° C and 50 ° C was also varied. This can be caused by a different initial water content of the materials. The C value in the desorption and adsorption samples shows the energy used to evaporate water in the monolayer area, in which the values were reduced while increasing in the storage temperature.

However, the K value increases as the storage temperature increased. This is consistent with the research of Villa-Vélez et al. (2012). The K value in this study ranged from 0.7 to 1, in agreement with the research of Timmermann et al (2001). The K value closer to 1 indicates that the pattern of water molecules binding in the monolayer area with free water is getting stronger. RMSE in the desorption and adsorption samples was less than 0.1. This shows that the GAB model can be used to clearly explain the isothermal behavior of moisture sorption from banana slices var. Raja Nangka.

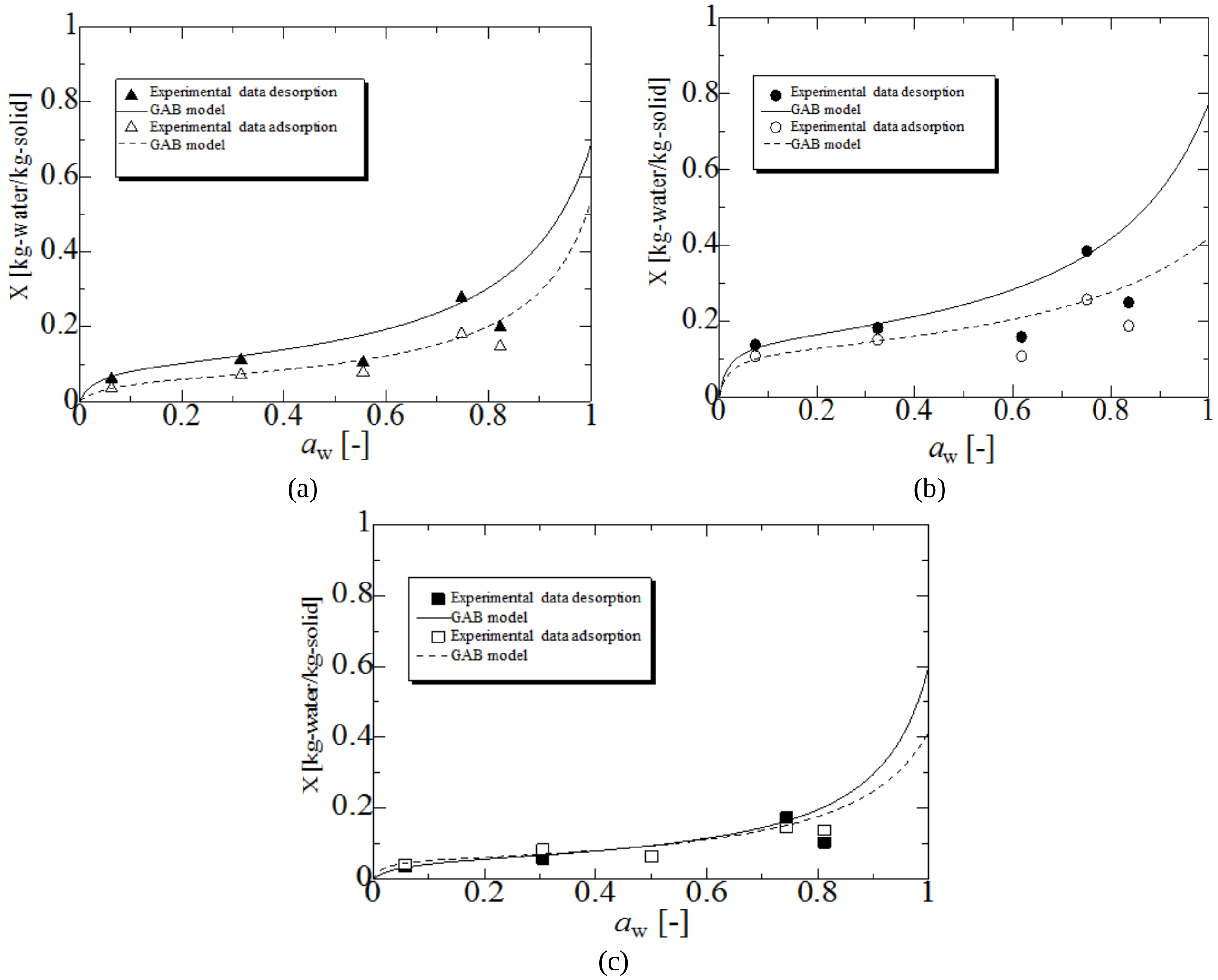

Figure 3. Hysteresis curve of moisture sorption isotherm of banana slices var. Raja Nangka at temperature: (a) 30 °C, (b) 40 °C and (c) 50 °C

Tabel 2. GAB modeling and error values of desorption and adsorption samples at 30, 40, and 50°C

Model	Constants	Desorption Samples		
		T = 30 °C	T = 40 °C	T = 50 °C
GAB	X_m (kg water/kg solid)	0.148	0.096	0.055
	C	66.18	34.15	23.70
	K	0.81	0.86	0.90
	R^2	0.4544	0.6905	0.5943
	RMSE	0.110	0.066	0.048
Model	**Constants**	**Adsorption Samples**		
		T = 30 °C	**T = 40 °C**	**T = 50 °C**
GAB	X_m (kg water/kg solid)	0.12	0.059	0.054
	C	67.88	21.87	75.53
	K	0.72	0.89	0.87
	R^2	0.4385	0.8155	0.8506
	RMSE	0.069	0.035	0.025

The RSME value of the desorption sample was higher than the adsorption sample. This is due to the high initial water content in the desorption sample during moisture isotherm testing. It is assumed that during testing, the moisture sorption isotherm of the desorption process was not fully achieved. Because the water content has saturated, this was supported with the

ANOVA analysis results at P-Value> 0.05 which indicated that the adsorption and desorption processes were not significantly different. R^2 values in both desorption and adsorption samples were below the R^2 standard (R^2 ≥0.7). This was occured due to the experimental data, particularly at a_w 0.61 and 0.83, was deviated from the predicted GAB model.

Conclusions

The GAB model can be used to explain the behaviour of the moisture sorption isotherm of banana slices var. Raja Nangka. The Xm values at temperature of 30, 40 and 50°C in the desorption samples were 0.148, 0.096, 0.055 (kg water / kg solid) and the adsorption samples were 0.12, 0.059, 0.054 (kg water / kg solid), respectively. The C values in the desorption samples were 66.18, 34.15, 23.70 and in the adsorption sample were 67.88, 21.87, 75.53. The K values in the desorption samples were 0.81, 0.86, 0.90 and in the adsorption samples were 0.72, 0.89, 0.87. Isotherm curves for desorption and adsorption of banana slices var. Raja Nangka at temperatures of 30, 40 and 50 ° C were categorised as type II (sigmoid).

Conflict of interest

The authors declare that there is no conflict of interest in this publication.

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