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Moisture Sorption Characteristics of Gluten-Free Flour

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Abstract

The quality of preserved flour is largely dependent on its moisture content, moisture migration and moisture uptake of the flour during storage. Therefore, the water activity level, which corresponds to a range of equilibrium moisture contents, must be determined by, for example, the use of moisture isotherms. The shape of the isotherm curve is dependent on the interactions between the vapour molecules and the solid material which can aid understanding of the mechanism taking place during water sorption. Moisture sorption isotherm of gluten-free flour was determined at three different storage temperatures (25°C, 35°C and 45°C) and relative humidity (10-85%), using the standard static gravimetric method. The GAB, modified Henderson, modified Oswin and modified Halsey sorption model were tested to fit the experimental data. A nonlinear regression analysis method was used to evaluate the constants of four sorption equations. The modified Oswin and GAB model were found to be acceptable in predicting the moisture sorption isotherms of gluten-free flour.
Keywords - Gluten-free flour, Sorption isotherms, relative humidity

1. Introduction

With increasing trends of celiac disease, a disorder induced by gluten-containing foods, such as barley, rye and, especially wheat that is widely used in the production of many processed foods, including baked foods, breakfast cereals, soup and snacks, celiac disease is recognized much more frequently in India, especially in northern region, not only in children but also in adults (Sood et al., 2003). Celiac disease is a gluten-elicited, autoimmune disorder of the small intestine, occurring in genetically predisposed individuals of all ages from middle infancy onward, that might cause severe malnutrition (Ludvigsson et al., 2012; Sapone et al., 2012). Further it is reported; newly diagnosed patients are often relieved to know that celiac disease can be treated by a gluten-free diet alone (Ciacci et al., 2002). Moisture sorption characteristics provide the necessary information regarding quality, stability and shelf life during packaging and storage of food powders. Hygroscopic nature of gluten-free flour causes for caking and follow deterioration by oxidation. The moisture content of the flour as a hygroscopic material exerts a strong influence on its quality and technological properties (Abdullah & Nawawi, 2000; Teunou & Fitzpatrick, 1999).

A moisture sorption isotherm explains the relationship between the water activity (a_w) and the equilibrium moisture content for a food product at a constant pressure and temperature. The knowledge and understanding of moisture sorption isotherms for food products is of great importance in design and optimization of processing as for instance in drying, for assessing packaging problems, for modeling moisture changes which occur during drying, for predicting shelf life stability, for ingredient mixing predictions etc. (Spiess & Wolf, 1983; Gal, 1987). Representation of sorption data with best fit sorption model could be used as a tool for achieving these designs.

The objective of the present study was to determine the sorption isotherms of gluten-free flour over a range of temperatures (25-45°C) and relative humidity (10-85%). The specific objective includes the presentation of influence of temperature on sorption isotherm and analyzes the data with the help of four sorption isotherm equations available in the literature and finds the most suitable model describing the isotherm of gluten-free flour.

2. Materials and Methods

2.1 Materials

The material used to study the sorption characteristics was gluten-free flour that was procured from market, Jaipur. The initial moisture content of the flour was 9.58% wet basis. AOAC (1990) standard procedures were used for the determination of crude fat– 3.46%, protein–12.19%, carbohydrate–75.71% and ash–1.29%.

2.2 Experimental procedure

The equilibrium moisture content was determined by standard gravimetric method by exposing the Gluten-free flour to constant relative humidity environment created by saturated solution of a particular salt at three different temperatures, viz., 25, 35 and 45°C (Bell & Labuza, 2000). Eight different salts viz., NaOH, CH3COOK, MgCl2, K2CO3, Mg(NO3)2, NaNO3, NaCl and KCl were used to maintain respective water activity (a_w) inside separate vacuum desiccators in the range of 0.10 to 0.85. Gluten-free flour was kept inside the desiccators for about 5-7 days for equilibration and final moisture content for each replicate was determined by oven drying method at 105°C for 24 hours. Each set of experiment was repeated thrice and mean values were recorded.

2.3 Fitting of EMC data to various sorption isotherm models

Experimental data were fitted to four moisture sorption isotherm models, such as Guggenheim-Anderson-De Boer (GAB), modified Henderson, modified Oswin and modified Halsey models (Table 1), where a_w represents the equilibrium relative humidity in decimal; M is the equilibrium moisture content in % (db); t is the temperature in °C; A, B, C are sorption isotherm constants specific to each equation. Non-linear regression analysis was used to calculate the respective constants using software like, Microsoft excel 2007 (Microsoft Corp., USA), Systat 8.0 (SPSS, Inc., 1998), and Origin 6.1 (Origin Lab Corporation, Northampton, MA 01060, USA, 2000).

Table 1: Mathematical models applied to the sorption isotherms to analyze EMC-a_w data for Gluten-free flour

Model	Mathematical Equation
GAB	$M = \frac{ABCa_w}{[1-Ba_w][1-Ba_w+BCa_w]}$
Modified Henderson	$1-a_w = \exp[-A(t+B)M^C]$
Modified Oswin	$M = (A+Bt)\left(\frac{a_w}{1-a_w}\right)^C$
Modified Halsey	$a_w = \exp\left[\frac{-\exp(A+Bt)}{M^C}\right]$

2.4 Goodness of fit to the sorption isotherm models

Statistical validity of the fit to the models was evaluated using statistical parameters such as the root mean square error (RMSE) and from determination of co-efficient (R^2) and mean relative error (MRE).

$$MRE = \frac{100}{N}\sum\left|\frac{M_e - M_p}{M_e}\right| \quad \text{... (1)}$$

$$R^2 = \frac{\Sigma(M_e - M_p)^2}{\sum M_e^2 \sum M_p^2} \quad \text{... (2)}$$

Where M_e is the experimental EMC value, M_p is the predicted EMC value and N is the number of experimental data. The value of R^2 close to 1, and that of RMSE value close to 0, indicate a better fit, MRE below 10% indicates a good fit for practical purposes (Lomauro et al., 1985).

3. Results & Discussion

3.1 Effect of temperature and relative humidity on equilibrium moisture content

The experimental results of Gluten-free flour each water activity (a_w) for three temperatures are given in Table 2 for sorption isotherm. The equilibrium moisture content at each aw represents the mean value of three replications. The mean of the equilibrium moisture content of Gluten-free flour ranged from 2.47 to 11.02, 4.43 to 12.63 and 4.35 to 14.21% (db) for the temperature of 25, 35 and 45°C respectively in the relative humidity range of 10-85%. The equilibrium moisture content increases with increase in temperature at constant relative humidity and increases with increase in relative humidity at constant temperature.

Table 2. Equilibrium moisture content M, % d.b. of Gluten-free flour obtained at different water activities and temperatures

Salt	25 °C		35 °C		45 °C	
	a_w	M^a	a_w	M^a	a_w	M^a
NaOH	0.113	2.47	0.112	4.43	0.111	4.35
CH_3COOK	0.237	3.78	0.215	4.62	0.197	5.58
$MgCl_2$	0.327	4.01	0.32	5.4	0.311	6.83
K_2CO_3	0.443	5.94	0.436	6.67	0.429	7.47
$Mg(NO_3)_2$	0.528	5.47	0.499	7.09	0.469	8.54
$NaNO_3$	0.742	8.24	0.72	9.75	0.699	11
NaCl	0.752	8.12	0.748	9.61	0.745	11.1
KCl	0.843	11	0.829	12.6	0.817	14.2

[a]*Mean of three replications*

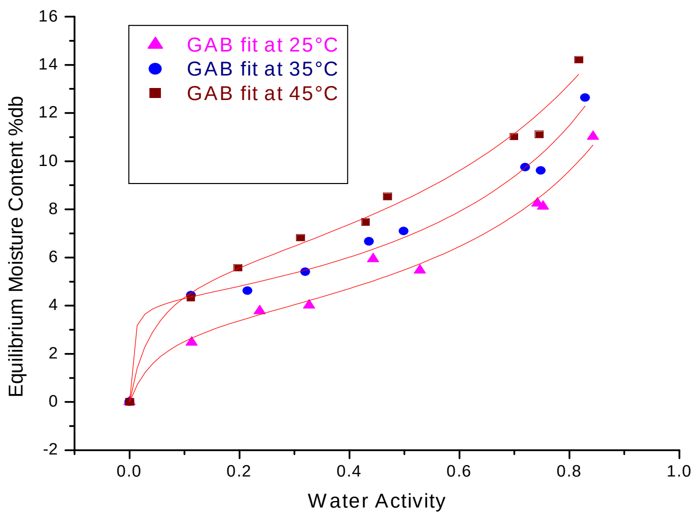

Fig 1: Sorption Isotherm of Gluten-free flour at 25°C, 35°C and 45°C

3.2 Fitting of sorption models to experimental sorption data

The results of nonlinear regression analysis of fitting the sorption equations to the experimental data are shown in Tables 3 and Table 4. The coefficients of the modified

GAB, modified Henderson, modified Halsey and modified Oswin models, their mean relative error (MRE), root mean square error (RMSE) and co-efficient of determination (R^2) were used to analyze the fitness of model. It is clear from this table that the modified Oswin model gives better fit to the experimental data with high R^2 and lowest values of MRE and RMSE than other models.

Table 3: Estimated parameters and comparison criteria for modified GAB model

GAB parameters	25 °C	35 °C	45 °C
M_O	3.46	4.262	5.824
C	22.235	282.846	31.924
K	0.8057	0.8036	0.7290
MRE (%)	6.0523	3.5122	3.6767
RMSE	0.4186	0.3291	0.4326
R^2	0.9894	0.9920	0.9843

Table 4: Estimated parameters and comparison criteria for modified Halsey, Henderson and Oswin model

Models	Model Parameters	Values
Modified Halsey	A	0.041
	B	1.311
	C	1.584
	MRE (%)	1.735
	RMSE	5.374
	R^2	0.970
Modified Henderson	A	0.815
	B	-11.499
	C	-1.664
	MRE (%)	3.667
	RMSE	4.182
	R^2	0.976
Modified Oswin	A	2.087
	B	0.144
	C	3.099
	MRE (%)	0.474
	RMSE	0.669
	R^2	0.995

Furthermore, quantitative evaluation of experimental sorption data provided on the basis of the GAB model is also good fit. Table 3 summarizes the estimated constants along with the mean relative error (MRE), root mean square error (RMSE) and co-efficient of determination (R^2). The low values of MRE (3.5122-6.0523), low value of RMSE (0.3291-0.4326) and correlation coefficients R^2 (0.9843-0.9920) close to unity indicate that GAB model is good fit to the sorption data, and the estimated parameters were statistically acceptable.

4. Conclusions

The moisture sorption isotherm of Gluten-free flour at different temperatures and water activities were determined by the standard gravimetric method using various saturated salt solutions. For Gluten-free flour there was a significant effect of temperature on the equilibrium moisture sorption in the range of temperatures studied. The equilibrium moisture content increased with increasing temperature at constant water activity. Among the sorption models chosen to test, modified Oswin and GAB model are suitable for describing the relationship between the equilibrium moisture content, water activity and temperature for Gluten-free flour.

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