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Modeling Sorption Isotherms of Refractance Window Dried Indian Jujube Powder

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Abstract—*This research work is focused on the basic measurement and modelling of sorption isotherms of Refractance Window (RW) dried jujube powder. Various statistical techniques used to ascertain the effectiveness of a model to describe the sorption data are discussed. The best fit mathematical model is GAB and Peleg equation are recommended to describe jujube powder isotherms. It is anticipated that this article will provide useful information to researchers pursuing work on sorption behaviour of jujube powder as well as modelling of sorption isotherms.*

Keywords: *GAB, Peleg.*

1. INTRODUCTION

The Moisture sorption isotherm is the relation between the equilibrium moisture content of a material (expressed as mass of water per unit mass of dry matter) and water activity, at a given temperature [1]. Since a_w is temperature dependent, it follows that temperature has a significant effect on sorption isotherms. So, when a food is subjected to an upward temperature shift, at any constant moisture content, a_w increases with increasing temperature [2]. Moisture sorption isotherms describe the relationship between a_w and the equilibrium moisture content of a food product. Knowledge of water sorption isotherms is of great importance to various food processes, including drying, storage and packaging [3]. They are useful to calculate time and energy consumptions during drying, to predict ingredients behavior upon mixing, to assist packaging selection, to model moisture changes during storage and predict shelf life of food products. Moreover, moisture content and water activity of a food influences texture, storage stability and its susceptibility to microbial spoilage. Refractance Window (RW) drying process was classified in the fourth generation of drying methods [4]. This process uses hot water as the source of heat and the temperature of water can be controlled as per requirement [5]. RW drying system utilizes circulating water at 95 to 97 °C as a means to carry thermal energy to materials to be dehydrated. Pureed products are spread on a transparent Mylar plastic conveyer belt that moves over circulating water in a shallow trough and the unused thermal energy in the circulating water is recycled. The actual product temperature is usually between 70°C and 80°C [6]. Jujube fruit of *Ziziphus jujube Mill.* (Rhamnaceae), also known as Ber, Indian pulm, Chinese date, or red date, has been widely used as food and herbal medicine for over 3,000 years [7]. It is a tropical/subtropical fruit native to the northern hemisphere. The genus *Ziziphus* has 135 to 170 species [8], of which 17 are native of India [9].

2. MATERIALS AND METHODS

Sorption Isotherms

Equilibrium moisture contents of powder at several a_w were determined by the static gravimetric method at different temperatures. Six saturated salt solutions were prepared corresponding to a range of a_w from 0.076 to 0.907 as shown in Table 1. Each solution was transferred into separated jars in such an amount to occupy a space of about 1.5 cm depth at the jar bottom. Triplicate samples of around 1g of dried powder weighed into small plastic receptacles and placed on tripods in the jars, then tightly closed and placed in a temperature-controlled chamber. The required equilibration time will be 4–5 weeks, based on the change in samples weight expressed on a dry basis, which did not exceed 0.1% (0.001 kg/kg dry solids). The equilibrium moisture content were determined in a vacuum oven, at 60˚C for 48 h [10] and maximum deviations of about 5% were observed between the triplicates.

Table 1: Saturated salt solution and their water activity

Sl. No	Name of Saturated salt solution	Water activity (30°C)
1	Sodium hydroxide (NaOH)	0.076 ± 0.021
2	Magnesium chloride ($MgCl_2$)	0.324 ± 0.002
3	Sodium nitrate $Na(NO_3)_2$	0.691 ± 0.002
4	Sodium chloride (NaCl)	0.751 ± 0.001
5	Ammonium sulphate$(NH_4)_2SO_4$	0.806 ± 0.003
6	Potassium sulphate (K_2SO_4)	0.970 ± 0.005

Isotherm Models

Seven sorption isotherm equations – Henderson, Oswin, Lewicki (two parameters), Lewicki (three parameters), Ferro-Fontan, Peleg and Guggenheim-Anderson-de Boer (GAB) was tested to fit dried powder sorption isotherm data. Model parameters were estimated by fitting the mathematical model to experimental data, using nonlinear regression. The adequacy of fitted functions evaluated by the determination coefficient (R^2) and the magnitude of the square of standard error (SSE) and RMSE.

Table 2: Sorption isotherm equations

Model	Expression	Reference
Henderson	$X = \left[\frac{\ln(1-a_w)}{A}\right]^{\frac{1}{B}}$	Henderson (1952)
Oswin (1946)	$X = A.\left[\frac{a_w}{1-a_w}\right]^B$	Oswin (1946)
Lewicki (two-parameters)	$X = A.\left(\frac{1}{a_w}-1\right)^{B-1}$	Lewicki and Wolf (1995)
Lewicki (three-parameters)	$X = \frac{F}{(1-a_w)^G} - \frac{F}{1+a_w^H}$	Lewicki (1998)
Peleg	$X = K_1.a_w^{n_1} + K_2.a_w^{n_2}$	Peleg (1993)
GAB	$\frac{(C-1).K.a_w.X_m}{1+(C-1).K.a_w} + \frac{K.a_w.X_m}{1-K.a_w}$	Van den Berg (1985)
Ferro-Fontan	$X = \left[\frac{\gamma}{\ln(A/a_w)}\right]^{1/r}$	Ferro-Fontan et al. (1982)

3. RESULTS AND DISCUSSIONS

Sorption Isotherms

Model fitting

Equilibrium moisture contents versus a_w for jujube powder at 30°C are shown in Table 3. The moisture content at each a_w represents the mean value of three replications. The standard deviations between triplicates were within a maximum limit of 4% from the average X_{eq} value, except for values corresponding to the lowest a_w, where the standard deviations attained up to 9% from the average X_{eq} value.

Table 3: Experimental equilibrium moisture contents (dry basis) for jujube powder at 30°C

Water Activity (a_w)	Equilibrium Moisture Content (X_{eq}) (g/dry weight g)
0.176	0.15
0.324	0.27
0.691	0.39
0.751	0.49
0.806	0.62
0.97	0.77

In the case of jujube powder, this behavior was not so pronounced, maybe due to physical and/or chemical damages that occurred during the drying process of powder, because the shape and position of the isotherms are influenced by the sample composition, physical structure (crystalline or amorphous), applied pre-treatments or processing.

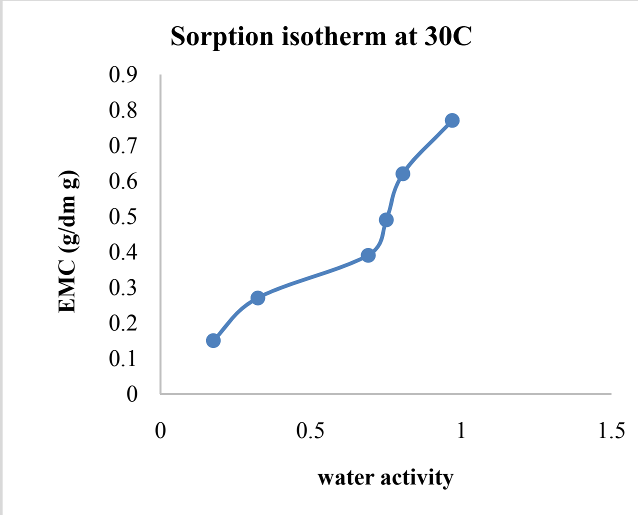

Figure 1: Sorption isotherm of RW dried jujube pulp at 30° C

The results of nonlinear regression analysis in order to fit mathematical models to the experimental data are shown in table 4. for jujube powder. Despite the fact all the tested models had presented satisfactory adjustments to experimental data, the GAB and Peleg equation are recommended to describe jujube powder isotherms, because they have been extensively used for foodstuffs, mainly for fruits and vegetables [11,12] as well as being simple and supplying parameters with physical meaning.

Table 4: Estimated parameters for RW dried jujube pulp at 30°C

Model	Parameter	Estimated values
Oswin (1946)	A	0.3242
	B	0.2488
	R^2	0.8687
	SSE	0.03242
	RMSE	0.09217
Henderson	B	1.928
	C	5.534
	R^2	0.9418
	SSE	0.01506
	RMSE	0.06136
Oswin	C	0.346
	N	0.2474
	R^2	0.8663
	SSE	0.0346
	RMSE	0.09301
Lewicki-2	A	0.3242
	B	0.7512
	R^2	0.8687
	SSE	0.03398
	RMSE	0.09217
Lewicki-3	F	0.8439
	G	0.09995
	H	0.9622
	R^2	0.9505
	SSE	0.01283
	RMSE	0.06539

Peleg	A	0.5111
	B	0.3155
	M	0.7058
	N	5.138
	R^2	0.9274
	SSE	0.01879
	RMSE	0.09692
GAB	C	7.299
	K	0.7056
	M	0.2584

Conclusion

The results of nonlinear regression analysis are fit for jujube powder. Despite the fact all the tested models had presented satisfactory adjustments to experimental data, the GAB and Peleg equation are recommended to describe jujube powder isotherms. The sorption isotherm study RW dried jujube powder can be used to select the packaging material and storage conditions, However, the process needs to scale up and the continuous RWD process further produce better results.

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