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Moisture Sorption Isotherms of Yogurt Powder Containing Candied Chestnut Puree

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ARTICLE INFO	ABSTRACT
	Yogurt powder was produced by freeze drying and with added candied chestnut puree at ratios of 5, 10, and 20 % by weight. Moisture sorption isotherms of yogurt powder samples, plain (YP), and containing 5, 10, 20% candied chestnut puree (CCP) were determined at 25°C using the standard, static-gravimetric method. The experimental adsorption data of yogurt powders at 25°C were fitted to 14 sorption equations which are most widely used to fit experimental sorption data of various food materials. The parameters of the sorption models were estimated from the experimental results by using the nonlinear regression analysis. The GAB model gave the closet fit to the sorption data of freeze dried yogurt powders with candied chestnut puree at 25°C. BET, Ferro Fanton, Henderson, Halsey, Oswin and Modified Oswin models are also acceptable for describing the adsorption isotherms for freeze dried yogurt with candied chestnut puree at 25°C.

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Introduction

With the increasing demand of healthy food products, studies in food science and technology are directed to the development of novel foods either new in composition or in the method of preparation. In the development of these novel foods the priority is usually given for the commonly preferred and consumed foods and the foods that are very important in health benefits. In Turkey, yogurt is among the most consumed foods; however, its consumption is mainly in plain form together with meals. For this reason improvement of yogurt with new additives may also increase its consumption among young people.

Yogurt is a food produced by bacterial fermentation of milk. The high nutritional value and health effect of yogurt make it a highly popular and worldwide consumed fermented food product. The shelf life of yogurt is one day when stored at ambient condition (25–30°C) and around 5 days at 7°C (Kumar and Mishra 2004) and its freshness is not retained for more than 1 week under refrigerated conditions (Kamruzzaman et al., 2002). Improvements in the shelf life of yogurt can be brought about by dehydrating and converting it into a shelf-stable powder. Yogurt can be dried by freeze, spray, microwave or convective drying methods. Dried yogurt in powder form have many applications such as filling in confectionery, ingredients for savory goods, biscuits, cakes, crackers and crisp breads in bakery and also used

as pastes in soups, sauces, dips, ready meals, baby foods etc. It can also be consumed directly after reconstitution (Koç et al., 2010). In addition to these, yogurt powder can be used as a functional food that can be mixed with dried fruit particles and nutritional ingredient to formulate a novel product and improve the reconstitution properties of the yogurt.

Addition of chestnut to yogurt may also be a good alternative to fruity yogurt which is very common in the food market. By this way yogurt will be enriched and its flavor will be improved. Chestnut is an important product in Mediterranean countries. Although changing on varieties and seasonal effects, on the average, chestnuts contain 50% moisture, 42% carbohydrates (28% starch and 14% sugars, mainly sucrose and in less proportion glucose and fructose), 2.5% proteins, 2% fats and the remaining minerals (Moreira et al., 2008; Chenlo et al., 2006). Due to its high moisture content chestnut is easily perishable after the harvest. The methods of preservation of the chestnut can be by drying, keeping in refrigerated storage rooms, in modified atmosphere (10% CO_2), and freezing. Chestnuts can also be canned, pureed, or preserved in sugar or syrup. Production and consumption of candied chestnuts is very common in Turkey. This product protects the nutritional value of fresh chestnuts and adds energy value due to the addition of sugar.

Food powders have an increasing importance in food processing due to their ease of storage and transportation, and their suitability for use in innovative formulations. Processing methods, like drying, homogenization, crystallization, powder production, and gelatinization change the microscopic structure of the food material (Jaya, 2009). The quality of a powdered food product is affected by the processing conditions, where the final quality is determined by its moisture content, water activity, color and the amount and quality of basic nutrients preserved. Most of the cases, the effect is based on moisture sorption isotherms and they are important in preservation, storage, packaging etc. (Tsami et al., 1990; Chirife and Buera, 1994; Vilades et al., 1995)

Food materials have specific equilibrium moisture content at a particular relative humidity or water activity. Moisture sorption isotherm represents the relationship between the equilibrium moisture content and relative humidity or water activity at a particular temperature (Kaymak-Ertekin, 2004; Varghese et al., 2009; Kumar and Mishra, 2006). Moisture sorption isotherm is unique for each food material and they are useful in understanding the behavior of food during its handling, drying, processing and storage systems (Chirife and Buera 1994; Vilades et al., 1995). The physical, chemical and microbiological stability of food depends on the water content and its interaction with the food component (Silva et al., 2014). For this reason, the data obtained from sorption isotherms help evaluate the storage stability and are also used in the process design and control (Paakkonen and Roos, 1990; Mrad et al., 2012). The data is also used in formulation of new products, selection of packaging materials and storage conditions, as well as in the drying processes (Demarchi et al., 2013). The shapes of the adsorption curves depend on the composition of the powdered product (Arslan and Toğrul, 2005). In addition the sorption isotherms can be used to determine the optimum moisture content of the dried product (Rockland and Nishi, 1980; Slade and Levine, 1991). For the above mentioned reasons, it is important to know the sorption characteristics of dried food materials. Although there are many studies about moisture sorption of food materials, a few of them were reported about the moisture sorption isotherms of yogurt powder (Kim and Bhowmik, 1994; Kumar and Mishra, 2006; Stencl, 2004; Varghese et al., 2009; Koç et al., 2010). Since the sorption behavior and the reconstitution properties of yogurt powder are affected by the drying method, particle size, and raw material properties, determination of the adsorption isotherms of yogurt powder is required for each yogurt product (Koç et al., 2010) with different compositions or method of preparation.

The water sorption in foods is a very complex phenomenon, consisting of several different mechanisms that depend on the material structure and composition. As a consequence, hundreds of models trying to represent the water sorption behavior in food matrices have been proposed. These models are generally classified into three categories: empirical, semi-empirical, and theoretical. As empirical two-parameter models Oswin, Smith and Henderson equations can be cited among many others. As a semi-empirical example, the Peleg model is given which has four parameters. And finally, derived from the Langmuir isotherm, two theoretical expressions can be cited: the BET and GAB equations, which are considered as the most used models to describe water sorption in food materials. The main advantage of theoretical models over the empirical and semi-empirical ones is the fact that their parameters have physical meaning. As a consequence, the inclusion of temperature dependency into the equation is possible, improving its fitting capability and most importantly, the parameters can provide essential information about the water state in the food. As an example, BET and GAB equations include the monolayer capacity or monolayer moisture content, M_0. This parameter constitutes very important information since it is directly related to the shelf life and stability of foods (Staudt et al., 2013). In a previous study, freeze drying of yogurt with chestnut puree was satisfactorily performed by testing the physical and powder properties of yogurt powder together by survival of lactic acid bacteria (Ergun et al., 2013). Freeze drying is considered as the reference process for manufacturing high quality dehydrated products. Compared to classical dehydration techniques, the main advantages of freeze drying process are; the preservation of initial raw material properties such as shape, appearance, taste, color, flavor, texture, biological activity etc. and the high rehydration capacity of the freeze dried product (Mosquera et al., 2012). However, freeze drying is the most expensive drying process and for this reason any further treatment in freeze dried products is not feasible. Therefore, it was assumed that the final product should be suitable for storing at room temperature and the adsorption experiments were performed at 25°C accepted as room temperature. The objectives of this study were to establish adsorption isotherms of freeze dried yogurt powder as plain and powder containing 5, 10 and 20% candied chestnut pure, and to determine the most appropriate model corresponding to the experimental data.

Materials and Methods

Materials

White, plain yogurt (14.2% (wet basis) total solids and 1.5% fat) was purchased from a local producer (Pinar Dairy Products Inc., Turkey) and kept at 4°C until used on the day of purchase. Candied chestnut puree containing 46.8% total sugar, 0.3% fat, 24.8% starch, and 0.9% protein was purchased from a local supermarket (Kardelen A.Ş., Turkey) and kept at 4°C in a closed container.

Preparation of Yogurt Mix

Yogurts both plain and mixed with candied chestnut puree at 5%, 10%, and 20% by weight were prepared by mixing the ingredients and poured on metal petri plates. Sample thickness was kept at a constant thickness of 3 mm by measuring with a digital caliper (Ergun et. al., 2013).

Freezing and Freeze Drying

The samples were frozen in an air-blast freezer (Frigoscandia, Helsinborg, Sweden) at -18°C for 2 hours, and freeze dried for 8 hours in laboratory scale equipment (Armfield Model-FT33 Vacuum Freeze Drier, England) at 13.3 Pa absolute pressure with a condenser temperature of -45°C. Samples were dried to constant weight. All freeze drying experiments were replicated as twice (Ergun et. al. 2013).

Determination of Sorption Characteristics

The adsorption isotherms of freeze dried plain yogurt powder and freeze dried yogurt powder containing 5, 10 and 20% candied chestnut puree were determined with the standard static-gravimetric method (Spiess and Wolf 1983; Labuza, 1984). Ten saturated salt solutions were selected to give relative humidity in the range of 0.11–0.87 at 25°C. Relative humidities of salt solutions at 25°C were taken from data reported by Greenspan (1977) (Table 1). A perforated and raised platform was put in each glass jar to support glass weighing dishes. The level of saturated salt solutions in each glass jar was kept below the perforated platform in order to avoid contact of the salt solution and the weighing dishes. A flask containing toluene was placed into the glass jars which have relative humidity higher than 50% in order to prevent mold formation (Labuza, 1984; Wolf et al., 1985; Rapusas et al., 1993). Three replications of the same experiment were carried out. The glass sorption jars were placed in a temperature-controlled cabinet at 25°C. The samples were weighed periodically (7-day intervals) with an electronic balance having an accuracy of 1 (mg) until they attained equilibrium. Equilibrium was reached when the difference in the sample weight between two successive measurements was less than the balance accuracy as 0.001 g. The equilibrium moisture content of the samples was determined by drying in a vacuum oven at 70°C for 4h. To establish moisture sorption isotherms, the equilibrium moisture contents were plotted against water activity.

Modelling Equations

A detailed search of the literature showed that moisture sorption isotherms of foods can be described by more than one sorption model (Kaymak-Ertekin and Sultanoglu 2001; Kaymak-Ertekin and Gedik, 2004). The criteria used to select the most appropriate sorption model were the degree of fit to the experimental data and the simplicity of the model. The experimental adsorption data of yogurt powders at 25°C were fitted to 14 sorption equations shown in Table 2. All equations in Table 2 were chosen because they are most widely used to fit experimental sorption data of various food materials. The parameters of the sorption models were estimated from the experimental results by using the nonlinear regression analysis (SPSS 15.0 for Windows) which minimizes the residual sum of the squares. Best fitting equations were evaluated with the mean relative percentage deviation (P) value (Eq. 15) and percentage root mean squares error (RMSE) value (Eq. 16). P value is defined as:

$$\%P = \frac{100}{N}\sum_{i=1}^{N}\frac{|M_{exp}-M_{cal}|}{M_{exp}} \quad (15)$$

and RMSE value defined as

$$\%RMSE = \frac{1}{N}\sum_{i=1}^{N}\left(\frac{|M_{exp}-M_{cal}|}{M_{exp}}\right)^2 \times 100 \quad (16)$$

Where M_{exp} and M_{cal} are experimental and predicted moisture content values, respectively, and N is the number of experimental data. A model was considered to be acceptable if the P values and RMSE values were below 10% and R^2 values were higher than 0.9 (Lomauro et al., 1985; Kaymak-Ertekin and Sultanoğlu, 2001; Kaymak-Ertekin and Gedik, 2004; Wang and Brennan 1991).

Results

The change of equilibrium moisture content with respect to a_w is given in Table 3 for yogurt powder samples, plain (YP), and containing 5, 10, 20% candied chestnut puree (CCP) at 25°C, where the equilibrium moisture content at each a_w represents the mean value of three replications. As expected, results showed that equilibrium moisture increases with the increase in water activity. At higher a_w values, equilibrium moisture increased, showing type II behavior according to the Brunauner, Emmett and Teller, (BET) classification. Most biological materials follow a sigmoid curve representing the type II isotherm of BET classification (Madamba et al., 1994). This finding is consistent with the results of Kumar and Mishra (2002), Varghese et al. (2009), Koç et al. (2010).

Table 1 Amount of salt and water to prepare saturated salt solution and water activity exhibited by saturated salt solutions at 25°C

Sample Number	Salt	Salt (g)	Water (g)	a_w
1	LiCl	150	85	0.113
2	CH_3COOK	200	65	0.226
3	$MgCl_2$	200	25	0.327
4	K_2CO_3	200	90	0.432
5	$Mg(NO_3)_2$	200	30	0.529
6	NaBr	200	80	0.576
7	$SrCl_2$	200	50	0.709
8	NaCl	200	60	0.753
9	NH_3SO_4	200	70	0.810
10	KCl	200	80	0.843

Table 2 Sorption models described sorption isotherms of food materials

Model Name	Equation	
GAB(Guggenheim-Andersen-de Boer) (Van den Berg, 1985)	$M=(M0*C*K*a_w)/((1-(K*a_w))*(1-(K*a_w)+(C*K*a_w)))$	(1)
BET (Brunauer, Emmett and Teller, 1938)	$M=(M0*C*a_w)/((1-a_w)+(C-1)*(1\ a_w)*a_w)$	(2)
Chung – Pfost (CHUNG and PFOST, 1967)	$a_w = \exp[-k / RT \exp(-cM)]$	(3)
Halsey (HALSEY, 1948)	$a_w = \exp(-k / M\ n)$	(4)
Henderson (HENDERSON, 1952)	$1-a_w = \exp(-k\ T\ M\ n)$	(5)
Iglesias- Chirife (IGLESIAS and CHIRIFE, 1978)	$\ln[M + (M^2 + M0.5)1/2] = k\ a_w + c$	(6)
Oswin (OSWIN, 1946)	$M = k(a_w / 1-a_w)\ n$	(7)
Modified Chung-Pfost (CHUNG and PFOST, 1967)	$M=(-1/n)\ln\{[-(T+c)\ln(aw)/k]\}$	(8)
Modified Halsey (HALSEY, 1948)	$a_w=\exp[-\exp(kT+c)M-n]$	(9)
Modified Henderson (HENDERSON, 1952)	$M=\{\ln(1-a_w)/[-k(T+c)]\}1/\ n$	(10)
Ferro Fontan (FERRO FONTAN et al., 1982)	$a_w=a/(Exp(b* M**-r))$	(11)
Peleg (PELEG, 1988)	$M=(k*a_w**n)+(c*a_w**b)$	(12)
Smith (ROCKLAND and STEWART, 1981)	$M=(a+b*T)-(c+d*T)*LN(1-a_w)$	(13)
Modified Oswin (OSWIN, 1946)	$M=(a+b*T)*(a_w/(1-a_w))**c$	(14)

* k, c, b and n, constants of sorption models; a_w., water activity ; M , equilibrium moisture content (dry basis) ; M0,5, moisture content when $a_w= 0,5$ (dry basis); R , gas constant (kJ/mol.K) and T, absolute temperature (K)

Table 3 Equilibrium moisture content (kg/kg dry solids) of freeze dried yogurt powder samples

a_w	YP	5%CCP	10%CCP	20%CCP
0.113	0.023±0.003	0.010±0.005	0.009±0.001	0.007±0.003
0.226	0.040±0.005	0.023±0.015	0.024±0.005	0.011±0.000
0.327	0.062±0.015	0.035±0.003	0.030±0.004	0.022±0.003
0.432	0.089±0.002	0.059±0.024	0.052±0.009	0.045±0.012
0.529	0.140±0.003	0.084±0.003	0.075±0.005	0.052±0.001
0.576	0.181±0.001	0.100±0.018	0.086±0.002	0.073±0.003
0.709	0.243±0.019	0.172±0.006	0.157±0.002	0.139±0.009
0.753	0.277±0.008	0.205±0.007	0.191±0.004	0.173±0.000
0.810	0.346±0.002	0.279±0.012	0.270±0.007	0.242±0.009
0.843	0.425±0.005	0.349±0.005	0.330±0.005	0.316±0.008

(YP: Freeze dried plain yogurt powder; 5%CCP:Freeze dried yogurt powder contain 5% candied chestnut puree; 10%CCP:Freeze dried yogurt powder contain 10% candied chestnut puree; 20%CCP:Freeze dried yogurt powder contain 20% candied chestnut puree)

As seen in the Figure 1, freeze dried plain yogurt powder has higher equilibrium moisture content (EMC) than freeze dried yogurt powders containing candied chestnut puree. Equilibrium moisture content of yogurt powders decreased with increasing of candied chestnut puree ratio. Although equilibrium moisture contents of yogurt powders containing candied chestnut puree are low, when water activity rises above 0.7, an increase in the equilibrium moisture content was observed.

In literature, "break point" was reported in the isotherms of dairy powders due to lactose crystallization (Berlin et al., 1968; Iglesias and Chirife, 1982; Foster et al., 2004). Such a break point was not observed in our study due to the low level of lactose in the fermented products by the action of culture organisms. Also Stencl (2004), Varghese et al (2009) and Koç et al. (2010) did not observe the break point in their experiment about the determination the moisture sorption isotherms of yogurt powder.

The sorption models presented in Table 2 were chosen to fit the experimental sorption data because they are the most widely used ones for several foods. Model parameters were estimated by taking the EMC to be the dependent variable. To calculate the parameters of the

equation, a nonlinear regression analysis minimizing the residual sum of squares was applied within the range of 0–0.9 water activity, except for the BET equation which is valid only for water activity below 0.5. The results of nonlinear regression analysis of fitting the sorption equations to the experimental data, the mean relative percentage deviation (P), RMSE, and correlation coefficient (R^2) values are presented in Table 4.

Experimental data were fitted to GAB equation and P values were calculated as 6.6, 2.3, 3.6, 9% and RMSE values were found to be 2.6, 0.7, 1.0, 1.8% for plain yogurt powder and yogurt powders containing 5, 10 and 20% candied chestnut puree, respectively. The GAB equation, the most widely used, seems to be most suitable to describe the moisture sorption isotherms of freeze dried yogurt powder for a wide range of water activity (0.11–0.87) with the least values for P% and RMSE on equilibrium moisture content (Table 4). Kumar and Mishra (2002), Varghese et al. (2009), Koç et al. (2010) reported that the GAB model gave the best prediction of the sorption data of yogurt powders. Also GAB model was found best fitted model for chestnut sorption (Vazquez et al., 2001). The experimental adsorption data and the predicted values obtained from GAB model at

25°C are also shown in Figure 1. The monolayer moisture content (M_0) helps to define physical and chemical stability of foods because it has a direct influence on enzyme activity, non-enzymatic browning, flavor preservation, and product structure. The GAB monolayer moisture contents for freeze dried yogurt powder were in the range of 0.063–0.114 kg/kg dry solid (Table 3). M_0 values decreased with increasing of candied chestnut puree ratio. Similar results have been reported in the study of Kumar and Mishra (2002) about determining the sorption isotherms of plain yogurt, mango–soy-fortified yogurt powder. According to their study, the monolayer moisture content of plain yogurt powder is higher than the others. Higher M_0 of may be due to considerably high sorption capacity through the swelling of colloidal material increasing more polar sites (Mishra et al., 1996). The GAB monolayer moisture content for spray dried yogurt powder was given as 0.136 kg/kg dry solid and the M_0 value obtained by the GAB equation was higher than that obtained by the BET model (Koç et al., 2010). In our study a similar trend was also observed for plain yogurt and M_0 values for both models are lower compared to spray dried yogurt. Kumar and Mishra (2006) reported that M_0 values estimated from the GAB model were between 3.02–1.79% (dry basis) for adsorption of convectively dried yogurt powder which are higher than our findings. The constants K and C for freeze-dried yogurt powders in the GAB equation varied in the range of 0.908-0.999 and 0.702-1.742 respectively. For spray dried yogurt powder K values of the GAB equation were expressed as between 0.85 and 0.91 (Koç et al., 2010). The value of K provides a measure of the interactions between the molecules in multilayer with the adsorbent and tends to fall between energy value of the molecules in the monolayer and that of liquid water.

The BET equation was fitted to four water activity values only because this model is valid for a_w below 0.5.

Since this equation is reported to be one of the most suitable models to describe the sorption behavior of food contains high amount of carbohydrates (Sopade and Ajisegeri, 1994; Al-Muhtaseb et al., 2002), it seems reasonable that it is suitable to describe the freeze dried yogurt powder with candied chestnut puree. M_0 value obtained from GAB equation is higher than the value obtained from BET equation for plain yogurt. The BET monolayer moisture contents for yogurt powder were 0.070–0.092 kg/kg dry solid for spray dried yogurt (Koç et al., 2010); in their study, it was also reported that, the M_0 value obtained by the GAB equation was higher than that obtained by the BET model. Basu et al. (2006) and Koç et al. (2010) also reported that the M_0 value given by the BET isotherms is always lower than the monolayer value derived from GAB and, reversibly, the BET value of energy constant is always higher than the GAB value. However, in our study, this behavior is not observed for the powders containing chestnut puree.

In addition to GAB and BET model, Ferro Fanton and Henderson models gave low RMSE% and P% values and the good regression coefficients. Moreover, Halsey, Oswin and the modified Oswin equations (Table 4) gave a satisfactory prediction of the adsorption equilibrium moisture content of freeze dried plain yogurt powder and freeze dried yogurt powder contain candied chestnut puree in different ratios. According to Koç et al. (2010), there is a good correlation between the experimental data and Oswin, Henderson and Halsey equations for spray dried yogurt powder studied at different temperatures within a wide water activity.

According to results of non-linear regression analysis, Smith, Iglesias-Chirife, Chung-Phost, Peleg, Modified Chung-Phost and Modified Halsey models failed to describe the sorption isotherms of freeze dried yogurt powder with candied chestnut puree, giving average values for P and RMSE above 10%.
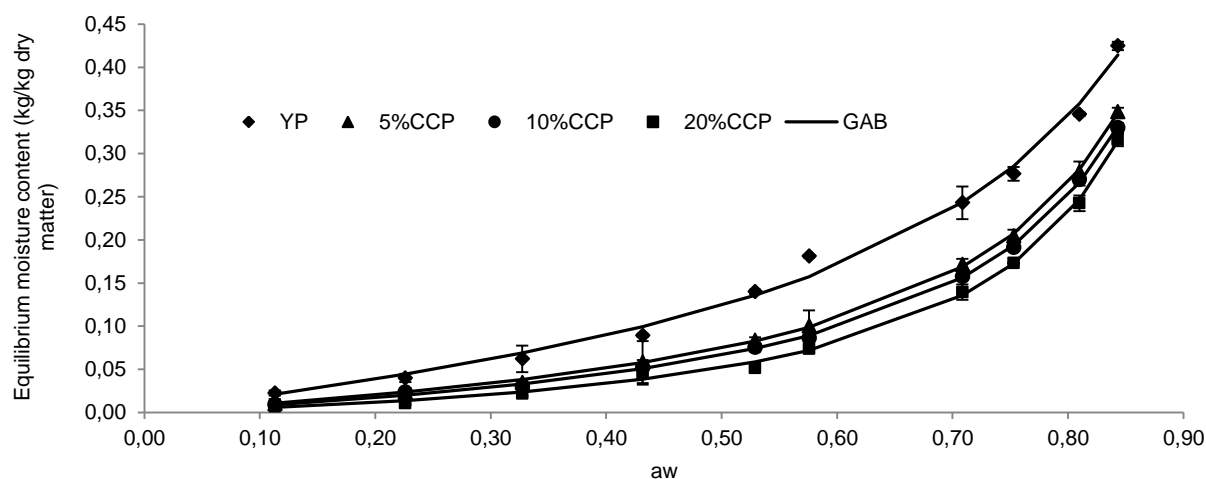

Fig. 1 Comparison of experimental and predicted from GAB model, adsorption equilibrium moisture contents of freeze-dried plain yogurt powder and frezee-dried yogurt powders contain 5, 10 and 20% candied chestnut puree at 25°C (YP: Freeze dried plain yogurt powder; 5%CCP:Freeze dried yogurt powder contain 5% candied chestnut puree; 10%CCP:Freeze dried yogurt powder contain 10% candied chestnut puree; 20%CCP:Freeze dried yogurt powder contain 20% candied chestnut puree)

Table 4 Estimated parameters, P (%), RMSE (%), and R^2 values of the sorption equations

Model	Parameters	Sample			
		YP	5%CCP	10%CCP	20%CCP
GAB	M_0	0.114	0.067	0.065	0.063
	C	1.742	1.321	1.098	0.702
	K	0.908	0.988	0.990	0.999
	R^2	0.993	1.000	1.000	0.999
	%P	6.565	2.340	3.675	9.029
	%RMSE	2.602	0.748	1.017	1.834
BET[*]	M_0	0.078	0.077	0.060	0.058
	c	2.382	0.970	1.246	0.005
	R^2	0.997	0.994	0.978	0.986
	%P	3.267	5.138	7.321	14.687
	%RMSE	0.745	0.845	1.407	1.713
MOD.OSWIN	a	16627.1	1233	7070	53
	b	-55.8	-4.139	-23.726	-0.176
	c	0.7	0.916	1.0	1.071
	R^2	0.992	1.000	1.000	0.999
	%P	10.552	3.121	3.923	9.429
	%RMSE	3.468	0.833	1.004	1.877
FERRO FANTON	a	1.772	1.397	1.298	1.327
	b	0.498	0.298	0.239	0.271
	r	0.443	0.475	0.509	0.430
	R^2	0.995	0.999	0.996	0.993
	%P	3.009	2.449	4.668	4.973
	%RMSE	2.245	1.623	3.202	3.636
HENDERSON	K	0.014	0.015	0.015	0.014
	n	0.855	0.730	0.714	0.624
	R^2	0.994	0.995	0.990	0.987
	%P	5.204	5.456	7.995	7.995
	%RMSE	3.858	3.673	4.608	6.192
SMITH	a	-0.314	0.782	-0.323	0.778
	b	0.001	-0.003	0.001	-0.003
	c	32.786	32.774	-32.842	33.019
	d	-0.109	-0.109	0.111	-0.110
	R^2	0.987	0.965	0.956	0.940
	%P	15.098	42.689	51.241	78.762
	%RMSE	4.881	10.177	11.439	15.178
IGLESIAS-CHIRIFE	k	1.344	1.491	1.514	1.705
	c	-1.280	-1.648	-1.718	-1.980
	R^2	0.936	0.882	0.865	0.846
	%P	18.126	24.569	26.351	28.265
	%RMSE	12.670	17.074	18.218	19.990
	$M_{0.5}$	0.125	0.076	0.069	0.049
CHUNG-PHOST	a	101.990	72.442	60.898	74.962
	b	-4.081	-2.899	-2.438	-3.000
	c	-28.333	-155.662	619.429	407.288
	d	1.142	6.234	24.784	-16.285
	R^2	0.987	0.965	0.956	0.940
	%P	15.098	42.689	51.241	78.758
	%RMSE	4.881	10.177	11.439	15.178
HALSEY	k	0.110	0.096	0.089	0.102
	n	0.829	0.734	0.735	0.622
	R^2	0.980	0.989	0.989	0.985
	%P	7.776	7.110	8.290	5.488
	%RMSE	5.297	5.289	5.888	4.692

OSWIN	k	0.124	0.074	0.067	0.052
	n	0.729	0.916	0.956	1.071
	R^2	0.992	1.000	1.000	0.999
	%P	10.552	3.121	3.923	9.429
	%RMSE	3.468	0.833	1.004	1.877
PELEG	k	4.482	3.492	3.309	2.316
	n	22.426	181.351	199.665	245.099
	b	1.743	3.096	3.335	3.930
	c	0.441	0.547	0.548	0.579
	R^2	0.997	0.978	0.979	0.982
	%P	10.056	29.214	31.418	34.733
	%RMSE	3.351	6.635	6.914	6.434
MOD. CHUNG-PHOST	a	0.024	0.021	0.005	0.022
	b	676.011	888.081	945.837	1001.612
	c	-24.987	-24.987	-24.997	-24.985
	R^2	0.965	0.934	0.921	0.900
	%P	13.554	18.386	20.074	22.084
	%RMSE	9.981	12.776	13.717	15.915
MOD. HALSEY	a	9294.387	13992.683	19538.135	-14377.200
	b	-371.883	-559.815	-781.634	574.981
	c	0.905	1.111	1.153	1.277
	R^2	0.984	0.997	0.997	0.996
	%P	21.957	18.367	16.337	23.386
	%RMSE	6.567	4.160	3.597	4.132

* a_w range is 0.11-0.5 for BET equation. First four data was used for equation; (YP: Freeze dried plain yogurt powder; 5%CCP:Freeze dried yogurt powder contain 5% candied chestnut puree; 10%CCP:Freeze dried yogurt powder contain 10% candied chestnut puree; 20%CCP:Freeze dried yogurt powder contain 20% candied chestnut puree)

Conclusion

The moisture sorption isotherms for freeze dried plain yogurt powder and freeze dried yogurt powder containing 5,10 and 20% candied chestnut puree have been obtained at 25°C. The sorption isotherms of freeze dried yogurt powders were typical type II sigmoidal curves according to the BET classification. The GAB model showed best fitting to the sorption data of freeze dried yogurt powders with candied chestnut puree in the water activity range of 0.11–0.87at 25°C. The adsorption data were also expressed by the BET equation in the range of water activity 0.1–0.5. Ferro Fanton, Henderson, Halsey, Oswin and Modified Oswin models are acceptable for describing the adsorption isotherms for freeze dried yogurt with candied chestnut puree at 25°C.

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