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Sorption isotherm characteristics of aonla flakes

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Abstract The equilibrium moisture content was determined for un-osmosed and osmosed (salt osmosed and sugar osmosed) aonla flakes using the static method at temperatures of 25, 40,50, 60 and 70 °C over a range of relative humidities from 20 to 90%. The sorption capacity of aonla decreased with an increase in temperature at constant water activity. The sorption isotherms exhibited hysteresis, in which the equilibrium moisture content was higher at a particular equilibrium relative humidity for desorption curve than for adsorption. The hysteresis effect was more pertinent for un-osmosed and salt osmosed samples in comparison to sugar osmosed samples. Five models namely the modified Chung Pfost, modified Halsey, modified Henderson, modified Exponential and Guggenheim-Anderson-de Boer (GAB) were evaluated to determine the best fit for the experimental data. For both adsorption and desorption process of aonla fruit, the equilibrium moisture content of un-osmosed and osmosed aonla samples can be predicted well by GAB model as well as modified Exponential model. Moreover, the modified Exponential model was found to be the best for describing the sorption behaviour of un-osmosed and salt osmosed samples while, GAB model for sugar osmosed aonla samples.

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List of symbols

M_e	: Equilibrium moisture content, decimal (dry basis)
M_e^*	: Equilibrium moisture content, (% d.b)
rh	: Equilibrium relative humidity, decimal
T	: Temperature (°K)
A	: Model equilibrium constant indicating sorption capacity
B	: Model equilibrium constant indicating temperature of environment
C	: Model equilibrium constant indicating relative humidity
b, c, h_1, h_2	: Constants
r^2	: Coefficient of determination
RMSE	: Root mean square error
P	: Mean deviation modulus (%)
UO	: Un-Osmosed aonla sample
Salt O	: Salt osmosed aonla sample
Sugar O	: Sugar osmosed aonla sample

The EMC has already been used in determining storage ability at various conditions (Labuza 1968), prediction of drying time (King 1968) and in general for the efficient design and operation of drying systems (Young 1976). The hysteresis effect is the differences between desorption and adsorption EMC values at the same equilibrium relative humidity (ERH). Several mathematical models/equations have been proposed to describe the isotherms for different types of biological materials. Chirife and Iglesias (1978) presented 33 such equations. Soysal and Oztekin (2001) evaluated seven equilibrium moisture content equations for

their ability to fit data for some medicinal and aromatic plants. They found the modified Halsey and modified Oswin equations to be the most versatile models for medicinal and aromatic plants. Menkov and Durakova (2007) fitted five mathematical models to the moisture equilibrium data of sesame flour and found GAB model to be the most suitable for describing the sorption data.

Aonla, a highly nutritive fruit with a great medicinal value and the richest source of vitamin-C is popular in different processed forms i.e murabba, pickle, juice syrup, squash and dehydrated powder. Preservation by drying is one of the ancient methods based on lowering moisture content in the product. Osmotic dehydration is one such technique with which wholesomeness of the final product can be achieved. Osmotic dehydration, recognized as a pre-concentration method to obtain better quality product by removing moisture under mild conditions and making the food stable when followed by hot air drying (Suresh and Sagar 2009). The dehydrated aonla produced for unani, ayurvedic medicines, inks, hair shampoos, dyes, hair oils, etc are subjected to different drying conditions and long-term storage. During that time, important physiochemical and biological changes take place with a strong impact on the colour and vitamin-C. Nevertheless, when osmotic dehydration is employed, while water removal does takes place, the acquisition of osmotic solute occurs in such a way that the composition of the final product is changed and the characteristics of the moisture sorption isotherm may be modified. Thus, it is necessary to investigate the equilibrium moisture content of aonla for various relative humidities and temperatures to enable the drying and storage conditions for the aonla fruit to be correctly specified. The automatic control of these conditions requires a reliable mathematical description of the EMC-ERH using suitable models. A number of models have been suggested in the literature for the dependence between the equilibrium moisture content (EMC) and the water activity (Berg and Bruin 1981). The modified Chung Pfost, modified Halsey, modified Henderson, modified Exponential and Guggenheim-Anderson-de Boer (GAB) equations which incorporate the temperature effect, have been adopted as standard equations by the American Society of Agricultural Engineers (ASAE) for the description of sorption isotherms (Menkov and Durakova 2007). Some work on sorption isotherm of processed fruits/vegetable like mushroom, berries, pumpkins figs and pears etc. have been reported (Khalloufi et al. 2000; Shivhare et al. 2004; Mayor et al. 2005; Pacco et al. 2008; Raquel 2009) and still much exhaustive study is required for adequate storage and packaging of fruits/vegetables based processed products. Thus, the present investigation was undertaken to evaluate the sorption isotherm characteristics of osmosed and un-osmosed dehydrated aonla flakes and to fit suitable equation using well known sorption models at various temperatures and RH.

Materials and methods

The static equilibrium method was used for determining isotherm characteristics of aonla flakes i.e. dried un-osmosed, salt osmosed and sugar osmosed samples prepared from 2 mm thick aonla slices. Incubator and hot air oven were used as temperature control chamber and the desiccators were used as humidity control chamber. The desired level of humidity was controlled through appropriate concentrations of aqueous glycerol solution; the tabulated data by Lapinski et al. (1976) was used (Table 1). The temperature and relative humidity within the desiccators was recorded with the help of electronic thermohygrometer having sensitivity of ±0.01. Experiments were conducted to standardize the concentrations of aqueous glycerol solution to achieve six levels (20, 40, 60, 70, 80 and 90%) of relative humidity values at five different temperatures (25, 40, 50, 60 and 70 °C) . The salt and sugar osmosed dried samples were prepared by giving osmotic pretreatment of salt and sugar separately at optimized conditions (osmotic solution temperature: 47 °C, solution concentration: 20%, solution to fruit ratio: 7, immersion time: 60 min for salt osmosed samples; and osmotic solution temperature: 44 °C, solution concentration: 60° Brix, solution to fruit ratio: 4, immersion time: 60 min for sugar osmosed samples) obtained by using multiple response optimization technique and were further dried to 10% (d.b) moisture content in a tray dryer at 60 °C. The samples were laid on mesh trays of the dryer in a single layer. The desired temperature was set by an automatic digital control and stabilized by keeping the dryer running for about fifteen minutes without any load.

Sample preparation for adsorption and desorption studies Proper conditioning procedures were adopted to ensure adsorption and desorption of the dehydrated aonla. To ensure adsorption at all temperature and relative humidity combinations, the samples were conditioned and brought down to 1.2% (d.b). To ensure desorption at all temperature and RH ranges, moisture content of un-osmosed, salt osmosed and sugar osmosed aonla samples was adjusted to 55, 65 and 35% (d.b) respectively by exposing the samples to a relative humidity of 80% and temperature of 25 °C (Patil and Grover 1986). The adjustment of moisture content for adsorption/desorption studies was based on the preliminary trials.

Experimental procedure Glycerol of desired concentration was transferred in the desiccators and the desiccators were

Table 1 Experimental and tabulated values of glycerol concentrations (by weight) for different relative humidity at different temperatures

Relative humidity (%)	Temperature (°C)							
	15		25		35		45	
	Glycerol concentration (%)							
	Exp	Lap	Exp	Lap	Exp	Lap	Exp	Lap
20	94.99	95.02	98.79	93.80	94.62	95.40	94.65	95.20
40	86.28	87.60	85.86	86.30	85.70	85.80	86.05	86.50
60	72.10	72.60	72.30	73.34	72.85	72.80	72.89	73.00
70	62.98	63.40	63.20	63.50	63.55	64.42	63.60	64.22
80	47.64	48.80	50.85	52.00	51.98	52.00	50.20	53.40
90	31.52	30.10	30.67	32.00	30.65	31.00	31.35	31.50

Exp: experimental value and Lap: Lapinski value (1976)

covered with lid and kept as such for moisture equilibrium at room temperature for 24 h and the duration was considered sufficient to create an atmosphere of the required relative humidity. About 5–7 g of test sample was taken in each petri dish/wire mesh and was placed in desiccators over the glycerol solution and was then covered by lids. The desiccators were then transferred into incubator/oven set at predetermined temperature. The weights of the samples were noted periodically until the change in weight reaches a constant value presuming that the required EMC has been attained. EMC of the samples was evaluated by oven drying the samples at 103 ± 2 °C for 16 h (AOAC 2000).

Validation of sorption isotherm models The experimental data was analysed using least square method (non-linear regression) of Statistical Package for Social Sciences (SPSS, version 11.0). The sorption isotherm (EMC) data obtained were fitted to the experimental data and validated to four three-parameter models and one five-parameter model (Table 2) commonly used for describing the sorption behaviour of a wide range of biological materials (Chung and Pfost 1967; Iglesias and Chirife 1976; Lazarides et al. 1995; Soysal and Oztekin 2001; Dhingra 2003; Basu et al. 2006; Jayaraj et al. 2007). Each of three constants of

models has a specific physical meaning. The parameter A represents the overall sorption capacity of the material at low relative humidity. The parameter B represents the effect of temperature and parameter C represents the effect of relative humidity (Hossain and Bala 2000; Prothon and Ahrne 2004).

Adequacy of fit of various empirical models Multiple non-linear regression module of Statistical Package for Social Sciences, (SPSS version 11.0) and NLREG version 6.01 was used to fit the equations to the experimental data for three-parameter and five-parameter model respectively. The coefficient of determination (r^2) and the plot of residuals were the primary and main criteria to select the best equation to account for variation in the EMC with temperature and relative humidity data. If the model is correct, then the residuals should be only random independent errors with a zero mean, constant variance and arranged in a normal distribution (Basu et al. 2006). In addition to coefficient of determination, the goodness of fit was determined by various statistical parameters such as RMSE and P as depicted from equations 1 to 3 (Gomez and Gomez 1983).

$$r^2 = 1 - \left\{ \frac{SS_{residual}}{(SS_{model} + SS_{residual})} \right\} \tag{1}$$

Table 2 Selected isotherm models

S. No.	Model	Equation
1.	Modified Chung Pfost	$Me = \left[\frac{1}{-B}\right] * \ln\left[\ln(rh) * \frac{(T+C)}{-A}\right]$
2.	Modified Henderson	$Me = \left[\frac{\ln(1-rh)}{-A(T+B)}\right]^{\left(\frac{1}{C}\right)}$
3.	Modified Halsey	$Me = \left[\frac{\exp(A-B*T)}{-\ln(rh)}\right]^{\left(\frac{1}{C}\right)}$
4.	Modified Exponential	$Me = \left[\frac{1}{-B}\right] * \ln\left[\ln(rh) * \frac{(T+C)}{-A}\right]$
5.	Guggenheim-Anderson-de Boer (GAB)	$Me* = \left[\frac{A*b*c*rh}{(1-b*rh)(1-b*rh+b*c*rh)}\right]$ $b = B\exp\left[\frac{h_1}{RT}\right]; c = C\exp\left[\frac{h_2}{RT}\right]$

$$RMSE = \left[\frac{1}{N} \sum_{i=1}^{N} (Experimental\ value - predicted\ value)^2 \right]^{1/2}$$

$$(2)$$

$$P(\%) = \frac{100}{N} \sum_{i=1}^{N} \left| \frac{Experimental\ value - predicted\ value}{Experimental\ value} \right|$$

$$(3)$$

Where, N is the total number of observations. The best model was selected as one with the highest r^2, least error values (RMSE and P) and random distribution of residuals.

Results and discussion

Effect of temperature and osmotic treatment on Me of aonla flakes The obtained mean values of Me based on

the triplicate measurements for the respective relative humidity and temperature for both adsorption and desorption are presented in Table 3. During osmotic dehydration using salt and sugar the solid content of the fruit increased by 3.5% and 12.0% respectively. The values of Me for aonla flakes varied from 1.24% to 62.28% (db) during adsorption process and 1.78% to 62.68% (db) for the desorption process irrespective of the treatment. Me increased with relative humidity but decreased with increased temperature. Vapour pressure of moisture within the product increases with temperature, thus hastening the transfer of moisture from the product to the atmosphere (Hossain and Bala 2000). The Me shift by temperature was mainly due to the change in water binding, dissociation of water or increase in

Table 3 Equilibrium moisture content (Me) of aonla flakes at several temperatures and relative humidities for adsorption and desorption

| T (°C)	rh (%)	Me[a](% d.b)					
		Un-Osmosed		Salt Osmosed		Sugar Osmosed	
		Adsorption	Desorption	Adsorption	Desorption	Adsorption	Desorption
25	20	3.98 (0.16)	4.14(0.10)	4.15(0.09)	4.24(0.13)	3.62(0.21)	3.88(0.18)
25	40	9.85(0.17)	9.95(0.05)	9.87(0.14)	9.98(0.16)	7.88(0.31)	8.08(0.24)
25	60	12.24(0.16)	13.32(0.21)	12.98(0.23)	14.14(0.12)	10.36(0.14)	11.92(0.17)
25	70	25.25(0.18)	26.64(0.12)	28.25(0.31)	30.12(0.54)	18.62(0.26)	19.68(0.19)
25	80	38.05(0.09)	39.26(0.07)	44.76(0.33)	15.1(0.23)	23.25(0.11)	24.02(0.18)
25	90	49.96(0.08)	50.05(0.13)	62.28(0.41)	62.68(0.54)	30.04(0.86)	30.54(0.38)
40	20	3.56(0.23)	4.12(0.25)	3.82(0.14)	4.04(0.16)	3.02(0.23)	3.58(0.34)
40	40	8.24(0.25)	8.52(0.17)	8.62(0.71)	8.72(0.56)	4.56(0.63)	4.86(0.57)
40	60	10.00(0.42)	10.24(0.09)	10.14(0.22)	10.32(0.12)	8.25(0.42)	9.42(1.12)
40	70	19.95(0.25)	19.98(0.28)	24.26(0.56)	24.84(0.31)	15.58(0.74)	17.05(0.33)
40	80	32.28(0.07)	33.05(0.14)	36.35(0.28)	37.02(0.55)	19.56(0.87)	20.23(0.46)
40	90	42.28(0.13)	42.98(0.26)	52.25(0.64)	62.24(0.38)	28.26(0.21)	28.78(0.24)
50	20	2.85(0.11)	2.96(0.26)	2.96(0.34)	3.02(1.00)	2.44(0.37)	2.85(0.42)
50	40	3.24(0.27)	3.37(0.24)	3.38(0.20)	3.42(0.72)	3.78(0.30)	3.38(0.15)
50	60	8.56(0.12)	10.12(0.41)	8.62(0.25)	9.15(0.21)	6.62(0.27)	6.88(0.21)
50	70	15.25(0.24)	17.14(0.26)	15.82(0.47)	16.82(0.13)	13.25(0.16)	14.74(0.31)
50	80	27.25(0.27)	28.00(0.54)	28.45(0.10)	28.96(0.08)	14.56(0.48)	14.88(0.42)
50	90	38.25(0.23)	38.82(0.23)	39.98(0.32)	40.08(0.10)	24.28(1.21)	24.98(0.07)
60	20	1.84(0.62)	1.92(0.08)	1.94(0.52)	1.98(0.38)	2.32(0.27)	2.52(0.22)
60	40	2.84(0.37)	2.97(0.33)	2.97(0.26)	3.02(0.40)	3.76(0.23)	3.86(0.13)
60	60	5.32(0.32)	6.18(0.16)	5.65(0.30)	6.32(0.29)	5.68(0.41)	6.15(0.14)
60	70	11.24(0.14)	12.31(0.27)	11.56(0.23)	12.88(0.24)	11.65(0.56)	12.25(0.21)
60	80	24.26(0.21)	25.15(0.19)	26.23(0.50)	26.83(0.60)	13.32(0.30)	14.05(0.23)
60	90	31.25(0.74)	31.68(0.31)	33.32(0.22)	33.84(0.13)	22.28(0.20)	23.12(0.10)
70	20	1.24(0.36)	1.85(0.56)	1.38(0.10)	1.78(0.35)	2.2(0.34)	2.32(0.35)
70	40	2.32(0.23)	2.56(0.13)	2.42(0.42)	2.62(0.42)	3.68(0.58)	3.92(0.23)
70	60	4.56(0.08)	5.24(0.11)	4.68(0.14)	5.12(0.22)	4.86(0.86)	5.84(0.20
70	70	9.42(0.06)	10.56(0.06)	9.86(0.23)	10.12(0.14)	10.35(0.34)	11.75(0.21)
70	80	22.25(0.13)	23.12(0.44)	23.26(0.33)	23.72(0.18)	12.25(0.21)	12.86(0.10)
70	90	28.35(0.33)	28.83(0.40)	4.15(0.30)	4.24(0.46)	20.24(0.24)	20.43(0.13)

[a] Mean of N=3 replications; Values in parenthesis are the standard deviation based on N=3 replications

solubility of solute in water (Pawar et al. 1992; Yu et al. 1999).

It is clear from Table 3 as well as Fig. 1 that the Me of salt osmosed aonla samples was more as compared to un-osmosed and sugar osmosed samples. It was observed that for both adsorption and desorption isotherms the difference in Me was non-significant irrespective of the treatment but for un-osmosed and sugar osmosed samples the difference was quite pertinent at higher relative humidity and the difference narrows down with the increase in temperature. This behaviour of water sorption isotherms may be due to

the changes in soluble solids composition and the prevailing presence of osmotic solutes in aonla samples. The observed difference in behaviour of sorption isotherms of osmo-convectively dehydrated product as compared to product simply dried in hot air might be due to the increased density, lowered shrinkage and porosity of osmo-convectively dried product as suggested by Sitkiewicz et al. (1996) on sorption isotherms of osmo-convectively dehydrated apples. The difference in sorption characteristics between salt and sugar osmosed samples may be due to the difference in molecular weight of solute i.e salt (58.4) and sugar

Fig. 1 Equilibrium moisture content isotherm with model fit for different treatments at 50 °C
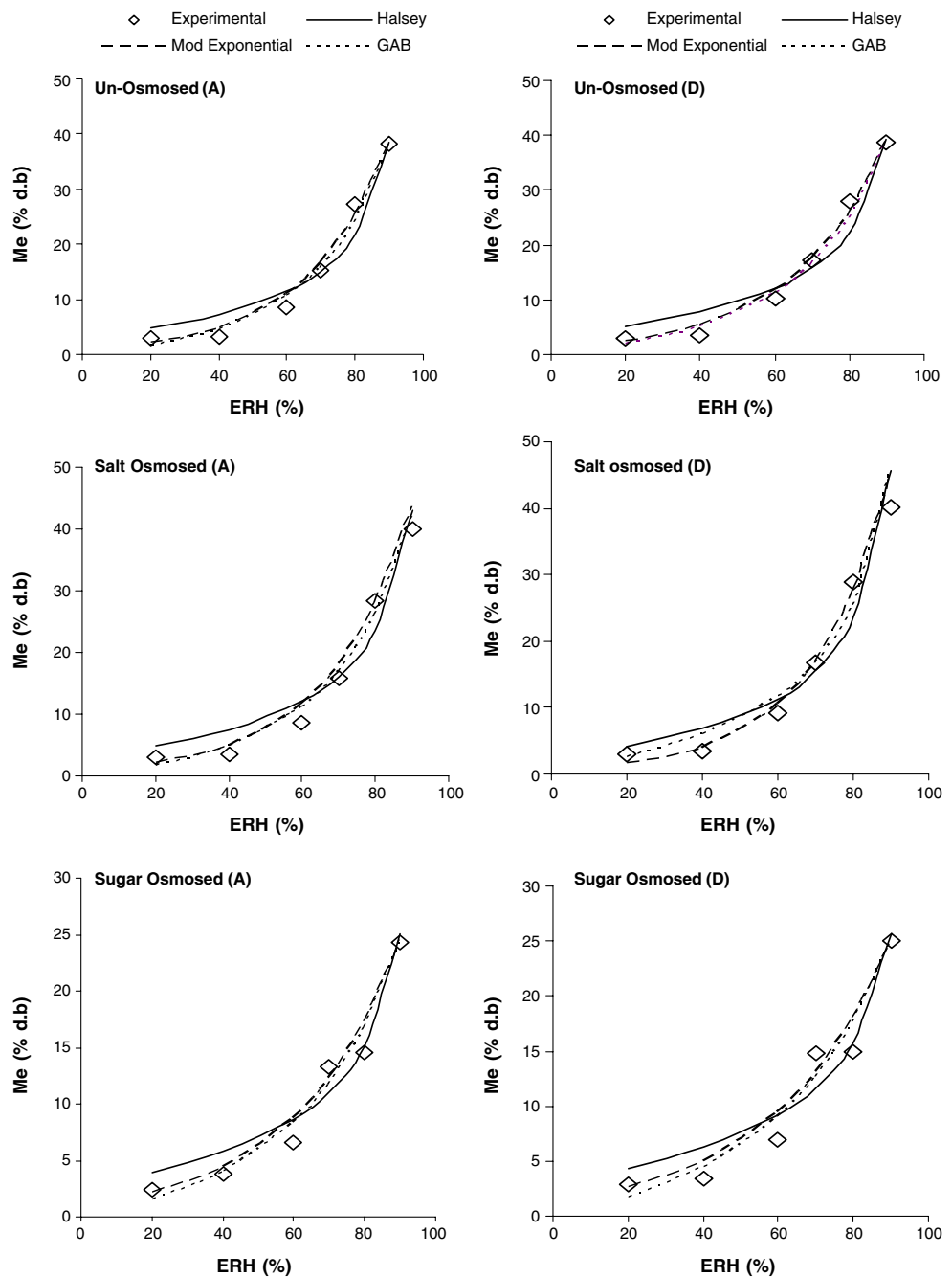
Table 4 Regression model coefficients (*A,B,C*), coefficient of determination (*r²*), root mean square error (*RMSE*) and mean deviation modulus (*P*) of three-parametric models for adsorption

Model	Treatment	A	B	C	r^2	RMSE	P
Modified Halsey	UO	2.475	0.018	1.296	0.94	0.037	45.10
	Salt O	3.857	0.022	1.239	0.94	0.041	43.45
	Sugar O	1.302	0.017	1.478	0.95	0.018	22.82
Modified Exponential	UO	0.052	0.00013	4.161	0.97	0.023	23.04
	Salt O	0.058	0.00015	4.406	0.97	0.026	22.33
	Sugar O	0.055	0.00014	3.424	0.97	0.013	13.29
Modified Henderson	UO	−20.109	−389.340	21.396	0.93	0.036	42.35
	Salt O	−14.109	−376.202	21.917	0.93	0.044	46.53
	Sugar O	183.343	−404.646	−4.276	0.97	0.015	16.00
Modified Chung-Pfost	UO	75.907	7.195	−265.866	0.90	0.044	70.66
	Salt O	64.899	6.290	−271.576	0.87	0.058	84.32
	Sugar O	98.206	11.890	−262.810	0.93	0.022	32.90

(342.2) infused in the fruit during drying resulting in decrease of Me for sugar (less hygroscopic flakes) and increase in Me for salt (more hygroscopic flakes) in comparison to un-osmosed flakes thus affecting its absorption/desorption potential.

Mould growth was observed on all the samples kept at 90% relative humidity at temperature of 25°C and was presumed not to have a significant impact on the final moisture content of the sample (Hutchinson and Otten 1984). The time required for equilibration varied from 9 to 15 days.

Hysteresis effect The presence of hysteresis effect shows that the sorption characteristics are dependent on the direction of attaining the equilibrium moisture content. In general, EMC in the adsorption phase was lower than in desorption. The magnitude of difference varied with the level of relative humidity and temperature. It was observed that the hysteresis effect decreased with increase in temperature as corroborated from Table 3. The hysteresis effect was statistically non-significant irrespective of the

treatments for the selected temperatures over the entire range of relative humidities, but was observed slightly between the range of 40–80%.

The hysteresis effect was observed prominently for un-osmosed and salt osmosed samples in comparison to sugar osmosed samples. The variation in adsorption and desorption isotherm was quite small for sugar osmosed samples irrespective of the temperature as corroborated from Table 3.

Model fitting of isotherms Both adsorption and desorption isotherm data were fitted to the modified Halsey, modified Exponential, modified Henderson, Chung-Pfost and GAB models. The coefficients for the three-parameter models, r², RMSE and P values are presented in Table 4 for adsorption and Table 5 for desorption. The coefficient for the five-parameter GAB model, r², RMSE and P are presented in Table 6 for both adsorption and desorption. Generally all the models showed high r² (>0.90) irrespective of the treatments used. For prediction of adsorption isotherm, it was observed that the modified

**Table 5** Regression model coefficients (*A,B,C*), coefficient of determination (*r²*), root mean square error (*RMSE*) and mean deviation modulus (*P*) of three-parametric models for desorption

Model	Treatment	A	B	C	r^2	RMSE	P
Modified Halsey	UO	2.492	0.019	1.339	0.93	0.037	41.99
	Salt O	1.695	0.015	1.133	0.89	0.055	36.70
	Sugar O	1.418	0.018	1.543	0.94	0.020	23.91
Modified Exponential	UO	0.061	0.00015	3.985	0.97	0.023	20.85
	Salt O	0.031	0.00008	4.845	0.89	0.054	27.21
	Sugar O	0.066	0.00016	3.236	0.95	0.014	13.34
Modified Henderson	UO	−19.923	−391.504	21.659	0.94	1.591	35.79
	Salt O	−24.555	−394.662	16.921	0.84	1.591	49.10
	Sugar O	193.664	−406.280	−3.962	0.96	1.591	16.48
Modified Chung-Pfost	UO	79.330	7.117	−265.258	0.91	0.042	59.31
	Salt O	89.066	6.267	−253.817	0.80	0.074	73.24
	Sugar O	101.363	11.665	−263.526	0.93	0.021	31.46

Table 6 Regression model coefficients (*A,B,C,h₁,h₂*) and error terms of Guggenheim-Anderson-de Boer (GAB) model

Isotherm	Treatment	A	B	$C(\times 10^{-5})$	h_1	h_2	r^2	RMSE	P
Adsorption	UO	36.617	1.206	2.852	−1228.40	24037.34	0.97	0.023	21.46
	Salt O	45.639	0.788	6.756	−64.68	21151.24	0.97	0.027	23.05
	Sugar O	16.235	1.077	4.942	−990.33	24718.27	0.98	0.012	16.35
Desorption	UO	41.051	1.188	4.502	−1264.16	22886.16	0.97	0.023	20.67
	Salt O	7.028	0.633	0.0008	1104.82	51657.31	0.90	0.056	24.10
	Sugar O	18.956	1.127	6.345	−1234.79	24142.77	0.97	0.014	16.27

Fig. 2 Model adequacy using plot of residuals at 50 °C for different treatments
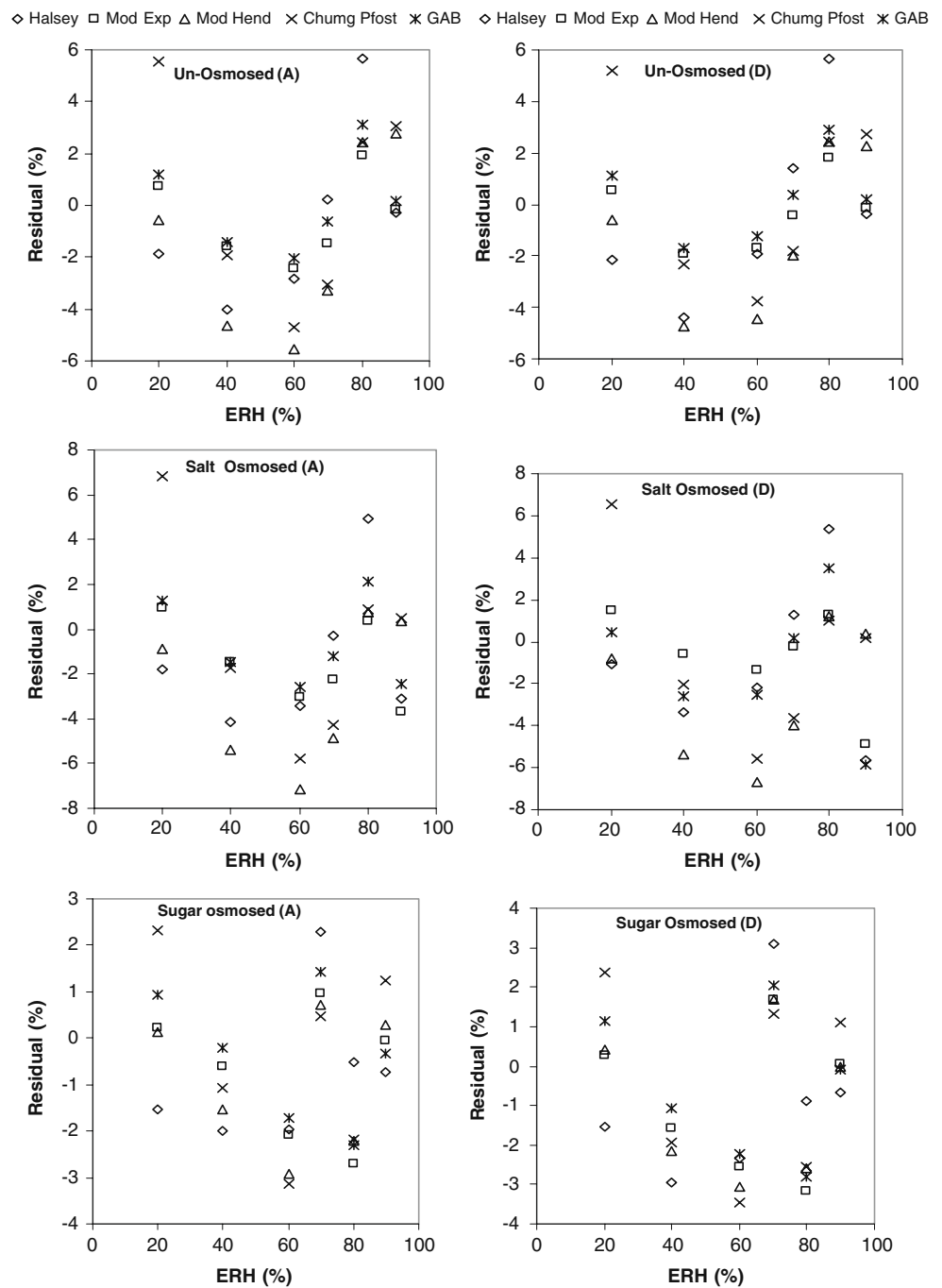
Exponential model as well as GAB model showed maximum r^2 (0.97, 0.97 and 0.97; 0.97, 0.97 and 0.98) values and minimum values of RMSE (0.023, 0.026 and 0.013; 0.023, 0.027 and 0.012) with acceptable mean deviation modulus (23.04, 22.33 and 13.29; 21.46, 23.05 and 16.35) for un-osmosed, salt osmosed and sugar osmosed aonla samples respectively, selecting it the best model representing the experimental data. Moreover, the same models were found appropriate to predict desorption isotherm of aonla witnessing highest r^2 and least values of error terms (Table 5).

It is clear from Fig. 1 that among the five isotherm models studied, the modified Exponential model as well as GAB model showed higher adequacy of fit between experimental and predicted isotherm data (both adsorption and desorption) for developed aonla flakes irrespective of the treatments. For adsorption and desorption of un-osmosed and salt osmosed samples the RMSE and P values obtained by GAB model was lower while for sugar osmosed samples the modified exponential model witnessed the best fit sowing maximum r^2 and minimum error values. The same results were supported by the distribution of residuals showing random pattern both for modified exponential model as well as GAB model (Fig. 2). Therefore, we recommend the GAB model for description of equilibrium isotherms for un-osmosed and salt osmosed samples and modified exponential model for sugar osmosed aonla flakes.

From the estimated parameters obtained during adsorption and desorption studies; as indicated in Tables 4 and 5, for the selected model (modified Exponential model); it can be concluded that relative humidity 'C' had maximum effect on Me of the product as compared to overall sorption capacity 'A' and temperature 'B' during storage of un-osmosed as well as osmosed dehydrated aonla samples whereas, the GAB model indicated sorption capacity to be the major parameter responsible for sorption behaviour of aonla flakes.

Conclusion

The Me of the aonla flakes did not equilibrate at same level during the adsorption and desorption isothermal process showing the existence of hysteresis effect. Among the osmosed aonla flakes sugar osmosed samples exhibited lower Me in comparison to salt osmosed samples indicating variation in its storage requirement. The GAB model exhibited the best ability to predict the moisture content at equilibrium for un-osmosed and salt osmosd aonla flakes while modified Exponential model showed good predictive accuracy for sugar osmosed samples.

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