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ADSORPTION ISOTHERMS OF KIWIFRUIT DRIED BY DIFFERENT DRYING METHODS

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Keywords
Kiwifruit, Adsorption isotherm, Freeze-drying, Vacuum-drying.

Abstract
The aim of this study was to determine the moisture adsorption isotherms of kiwifruit dried by hot air, vacuum and freeze drying methods. Equilibrium moisture contents (EMC) of dried kiwifruits were obtained by using the standard gravimetric method at two different temperatures (25 and 45°C) within a range of water activities from 0.112 to 0.936. The adsorption isotherms of dried kiwifruits decreased with increasing temperature and exhibited type III behavior. Six different isotherm equations (GAB (Guggenheim-Anderson-de Boer), BET (Brunauer-Emmett-Teller), Oswin, Henderson, Halsey and Peleg) were employed to describe the experimental adsorption isotherm data. Adsorption data obtained at both 25 and 45°C for vacuum dried samples and data obtained at 45°C for hot air and freeze dried samples were best represented by Peleg equation. For the samples dried by hot air and freeze drying, GAB equation gave the best description of the experimental data obtained at 25°C.

FARKLI KURUTMA YÖNTEMLERİ İLE KURUTULAN KİVİ MEYVESİNİN ADSORPSİYON İZOTERMLERİ

Anahtar Kelimeler
Kivi meyvesi, Adsorpsiyon izotermi, Dondurarak kurutma, Vakum kurutma.

Öz
Bu çalışmanın amacı, sıcak hava, vakum ve dondurarak kurutma yöntemleriyle kurutulmuş kivi meyvesinin nem adsorpsiyon izotermlerini belirlemektir. Kurutulmuş kivi meyvesinin denge nem içerikleri (EMC), standart gravimetrik yöntem kullanılarak, iki farklı sıcaklıkta (25 ve 45°C), 0.112 ile 0.936 su aktivitesi aralığında elde edilmiştir. Kurutulmuş kivi meyvelerinin adsorpsiyon izotermleri artan sıcaklık ile azalmış ve tip III davranış sergilemiştir. Deneysel adsorpsiyon izoterm verisini tanımlamak için altı farklı izoterm denklemi (GAB (Guggenheim-Anderson-de Boer), BET (Brunauer-Emmett-Teller), Oswin, Henderson, Halsey ve Peleg) kullanılmıştır. Vakumla kurutulmuş örnekler için 25 ve 45 °C'de elde edilen adsorpsiyon verileri ve sıcak hava ve dondurarak kurutulmuş örnekler için 45 ° C'de elde edilen veriler en iyi Peleg denklemiyle temsil edilmiştir. Sıcak hava ve dondurarak kurutma ile kurutulmuş olan örnekler için, GAB eşitliği, 25°C'de elde edilen deneysel verileri en iyi şekilde tanımlamıştır.

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1. Introduction

Kiwi is a common name for the plants in the cultivar group obtained from *Actinidia deliciosa*, which is a vine-like woody climber plant species. After the adaptation trials initiated in 1988, kiwi has been produced in the Black Sea, Mediterranean, Marmara and Aegean regions in Turkey. Among these regions, the Eastern Black Sea Region was found to be more suitable in terms of ecological requirements of the

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plant than in other regions. Kiwifruit has high content of glucose, fructose (Castaldo et al., 1992), organic acids (Esti et al., 1998), vitamin C and bioactive phenolic compounds that has a beneficial effect on human health with its antioxidant activity (Wang et al., 1996; Kubal et al., 2017).

Drying is a process which can be applied to extend the shelf life of fresh kiwifruit with a convenience of preservation at ambient temperature. The physical, chemical and microbiological stability of dehydrated fruit is strongly affected by the relative humidity and the temperature of the storage environment. Moisture sorption characteristics describe the moisture exchange between the food and the environment and provide significant information to predict shelf-life stability of food matrixes. The relationship between water activity and equilibrium moisture content of a food can be described by the moisture sorption isotherms at a given temperature (Al-Muhtaseb et al., 2002). It is known that the food composition and drying method affect the sorption characteristics as well as some quality characteristics of the end product (Kingsly et al., 2009; Ciurzynska et al., 2012; Udomkun et al., 2015). Sorption isotherms alter depending on drying method and temperature.

The most commonly used method to determine the moisture sorption isotherms of fruits is the gravimetric method in which the food sample is kept in an environment with a constant relative humidity and the weight loss or gain is monitored statically or dynamically. Usually saturated saline solutions are used to obtain the environments with constant water activity in the range of 0.01-0.90 (Erbaş et al., 2016). The weight of food sample changes when maintained at different water activity environment until equilibrium. After a while, the moisture migration between the saturated salt solution and the food will reach equilibrium and there will be no change in weight. The moisture content calculated according to the final sample weight is the equilibrium moisture content (EMC). The curve obtained by plotting the EMC values against water activity values is called the sorption isotherm. The mathematical equations describing the moisture sorption isotherm of foods are important for the drying and storage processes, the estimation of drying time or the shelf life of the dried product. Several models are available in literature to describe the moisture sorption data such as GAB, BET, Iglesias-Chirife, Caurie, Langmuir, Chung-Pfost, Simit, Henderson, Halsey, Peleg, Oswin, etc. However, none of these models give an exact result for all types of water activity and for all types of food. The reason for this is that foods are highly heterogeneous in structure and composition (Al-Muhtaseb et al., 2002; Erbaş et al., 2016). According to literature, the best fit model defining the sorption isotherm of dried fruits varies according to the type of fruit, sorption temperature, and drying method.

In a study, the sorption isotherms of the strawberries in different temperatures (50 and 70°C) and pressures (4-16kPa) were determined at 25°C (Ciurzynska et al., 2012). The obtained isotherms were found as similar to the typical Sigmoid type (S-shaped), in other words Type II isotherm. It was determined that there was no effect of the applied pressure on the moisture absorption capacity of the dried strawberry samples while increasing drying temperature significantly altered the moisture sorption capacity. Five different models (Oswin, Halsey, Lewicki, Peleg and GAB) were examined to simulate the experimental data and Lewicki model was found to be most suitable for best representation of experimental data. Udomkun et al. (2015) investigated the sorption characteristics of fresh, osmotically-pretreated and dried papaya samples. Sorption isotherms of papayas, dried with hot air at 70°C after osmotic pre-drying, were obtained at temperatures of 30, 50 and 70°C. The Halsey was found to be the best model that explained the sorption behavior of dried papayas. Fresh samples were best represented by the Oswin model. Kaya et al. (2010) obtained sorption isotherms for kiwi slices dried by hot air at five different temperatures as 25, 35, 45, 55, 65°C. At a certain relative humidity, it was observed that there was a decrease in the moisture sorption degree with increasing temperature. In another study, adsorption isotherms of sun-dried tomato, pepper and eggplant were obtained at 25°C and 11-90% relative humidity (Koroş, 2007). The adsorption isotherm of the dried tomato was found to be consistent with the typical S-shaped Type II isotherm, while the isotherms for dried peppers and eggplant were found to be similar to the J-shaped Type III isotherm. It was stated that GAB model was the best fit model for the experimental data among four models as linearized Brunauer-Emmett-Teller (BET), nonlinear Guggenheim-Anderson-de Boer (GAB), Oswin and Halsey models used for dried vegetables.

The aim of the present work was to investigate the effect of different drying methods (hot air drying, vacuum drying and freeze drying) on the moisture adsorption isotherms of kiwifruits. The adsorption isotherms of dried kiwifruits were obtained at two different temperatures (25 and 45°C). Six different sorption models (GAB, BET, Halsey, Oswin, Henderson and Peleg) were investigated to reveal the best fit model to the experimental adsorption data.

2. Materials and Methods

2.1. Materials

Kiwifruits (*Actinidia deliciosa*) used in this study were obtained from a local market and stored at 4±0.5°C until further use. The peeled kiwifruits were sliced into 5 mm of thickness and approximately 50 mm in diameter. The initial moisture content of kiwifruit was determined as 80.6 ±0.5 % by drying to a constant weight in a vacuum oven at 70°C. Analytical grade potassium chloride, sodium chloride, potassium nitrate from Sigma Aldrich (St. Louis, United States), magnesium nitrate, lithium chloride from Merck (Darmstadt, Germany) and magnesium chloride, potassium carbonate, sodium nitrite from Kimetsan (Ankara, Turkey) were used for the preparation of saturated salt solutions.

2.2. Drying experiments

The kiwifruit slices were dried using three different drying methods (hot air drying, vacuum drying and freeze drying) until the final moisture content of about 10% to be reached. Hot air drying was performed in a lab-scale oven at 60°C where the kiwifruit samples were spread uniformly in a single layer on a tray (Maskan, 2001; Kaya et al., 2010). Vacuum drying was performed in a vacuum oven (Memmert VO 500, Germany) at 60°C and a vacuum pressure of 100mbar. Freeze drying was carried out in a lab-scale freeze dryer (FreeZone 2.5L 7670530, Labconco) at -50°C and 0.1 mbar vacuum pressure.

2.3. Determination of adsorption isotherms

The standard gravimetric method recommended by the COST 90 project (Wolf et al., 1985) was used to determine the moisture sorption isotherms at 25°C and 45°C. The whole dried sample was weighted in perforated aluminum cups and placed on a platform inside sealed containers with different levels of relative humidity maintained by eight different saturated salt solutions (Tatar et al., 2014; Yogendrarajah et al., 2015). Selected salts used for the preparation of saturated salt solutions and their corresponding equilibrium relative humidity at the experimental temperatures were presented in Table 1. To prevent mold or bacterial growth, capillary tube containing toluene (3ml) was also placed in each container with high equilibrium relative humidity (ERH≥60%) (Sahin and Sumnu 2006; Yogendrarajah et al., 2015; Tatar et al., 2014). The sample weight was recorded at regular intervals until the equilibrium was achieved. Equilibrium was considered to have been reached when the change in the sample weight between two successive measurements was less than 1%. Equilibrium conditions were attained within 2 months for all samples. The EMC of each sample was determined by using a vacuum oven at 70°C and 100mbar. The average values of two replications were used in the analysis.

Table 1. Equilibrium relative humidities (ERH) (%) of saturated salt solutions

SALT	TEMPERATURE		REFERENCE
	25°C	45°C	
Lithium Chloride (LiCl)	11.30	11.16	Greenspan, (1977)
Magnesium Chloride ($MgCl_2$)	32.78	31.10	Greenspan, (1977)
Potassium Carbonate (K_2CO_3)	44.30	42.90	Labuza et al., (1985)
Magnesium Nitrate ($Mg(NO_3)_2$)	52.89	46.93	Greenspan, (1977)
Sodium Nitrite ($NaNO_2$)	64.40	60.50	Young, (1967)
Sodium Chloride (NaCl)	75.29	74.52	Greenspan, (1977)
Potassium Chloride (KCl)	84.34	81.74	Greenspan, (1977)
Potassium Nitrate (KNO_3)	93.58	87.03	Greenspan, (1977)

2.4. Modelling of sorption isotherms

Experimental EMC data were fitted to six widely used moisture sorption isotherm models describing the sorption isotherms of foods (Table 2) (Al-Muhtaseb et al., 2002; Andrade et al., 2011; Kaymak-Ertekin and Gedik, 2004).

Table 2. Equations used to model the moisture adsorption isotherms of dried kiwifruit

MODEL	EQUATION	NO
GAB	$EMC = \frac{M_0 \times K \times C \times a_w}{(1-K\times a_w)\times[1+(C-1)\times K\times a_w]}$	(1)
BET	$EMC = \frac{M_0 \times C \times a_w}{(1-a_w)\times[1+C\times a_w - a_w]}$	(2)
Oswin	$EMC = C \times (\frac{a_w}{1-a_w})^n$	(3)
Halsey	$EMC = (\frac{-C}{ln a_w})^{\frac{1}{n}}$	(4)
Henderson	$EMC = (\frac{-\ln(1-a_w)}{C})^{\frac{1}{n}}$	(5)
Peleg	$EMC = C_1 a_w^{C_3} + C_2 a_w^{C_4}$	(6)

where EMC is the equilibrium moisture content (g H_2O/g dry solid), a_w is the water activity and M_0, K, C, C_1, C_2, C_3, C_4, n are equation constants.

The nonlinear regression analysis was performed using a MATLAB software (R2018b, Mathwork, Inc., MA, US). To evaluate the accuracy of fit of the selected models, the statistical parameters, the coefficient of determination (R^2), the sum of square error (SSE), the root mean square error (RMSE) and mean relative percent deviation modulus (P%) were calculated by using the following formulas.

$$SSE = \sum_{i=1}^{N}\left(EMC_{exp,i}\text{-}EMC_{pred,i}\right)^2 \quad (7)$$

$$R^2 = 1 - \left[\frac{\sum_{i=1}^{N}\left(EMC_{exp,i}\text{-}EMC_{pred,i}\right)^2}{\sum_{i=1}^{N}\left(EMC_{exp,i}\text{-}EMC_{mean}\right)^2}\right] \quad (8)$$

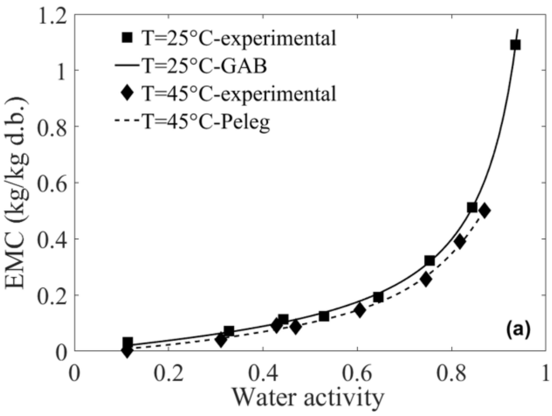
$$RMSE = \left[\frac{SSE}{\nu}\right]^{\frac{1}{2}} \quad \text{where } \nu = N - m \quad (9)$$

$$P(\%) = \frac{100}{N}\sum_{i=1}^{N}\frac{\left|EMC_{exp,i}\text{-}EMC_{pred,i}\right|}{(EMC_{exp,i})} \quad (10)$$

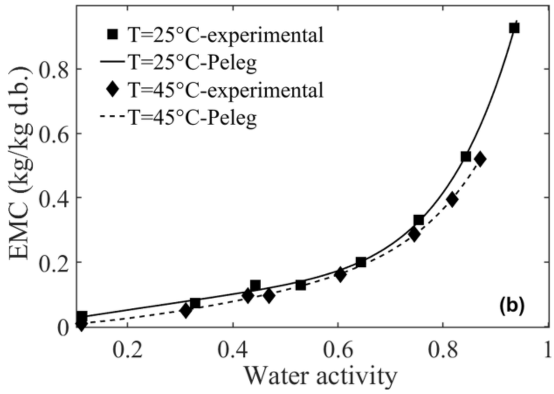
where N is the number of experimental data points, m is the number of fitted coefficients in each equation, EMC_{mean} is the mean of experimental EMC values, $EMC_{exp,i}$ and $EMC_{pred,i}$ are the ith experimental and predicted equilibrium moisture content values, respectively.

3. Results and Discussion

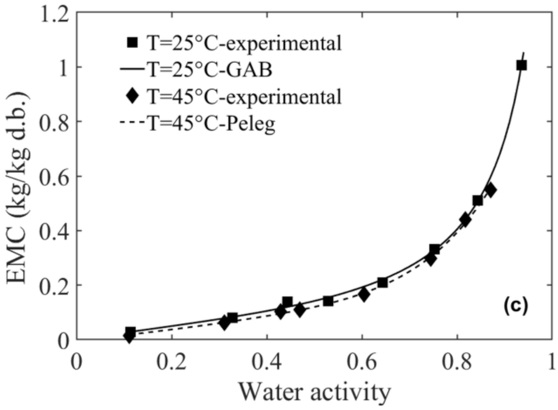
Adsorption isotherms of dried kiwifruit slices obtained at 25°C and 45°C are shown in Figure 1. At all temperatures, EMC's of dried kiwifruit samples increased slowly up to water activity of nearly 0.85 which is followed by a steep rise. Although most food products generally show typical type II (sigmoid-shaped) adsorption isotherms (Andrade et al., 2011; Al Mutaseb et al., 2002), adsorption isotherms of dried kiwifruit slices followed type III (J-shape) isotherm according to BET classifications. In literature, similar to this study, adsorption isotherms of some dried fruits like apple and mango (Falade et al., 2004a, Akoy and von Hörsten, 2013), pineapple (Falade et al., 2004b), papaya (Thalerngnawachart and Duangmal, 2016), pear (Mitrevski et al., 2015), blueberries (Lim et al., 1995) exhibited type III (J- shaped) behavior. Type III isotherms describes foods rich in soluble components such as sugars (Labuza et al., 1985; Chinachoti et al., 1984). Kaymak-Ertekin and Gedik (2004) obtained adsorption isotherms of vacuum dried apples, apricots, grapes and potatoes at 30, 45 and 60°C and recorded that fruits rich in sugar showed type III isotherm. Type III isotherm shows slow moisture gain up to the deliquescent point where the adsorbed water begins to dissolve the sugar crytals (Labuza and Altunakar, 2008; Van Campen et al., 1983) and rapid moisture uptake after that point. The drying method did not change the shape of adsorption curves of dried kiwifruit.



(a)



(b)



(c)

Figure 1. Moisture adsorption isotherms of kiwifruit dried by hot air drying (a), vacuum drying (b) and freeze drying (c) methods.

Six models were applied to the experimental adsorption data obtained at two different temperatures. Model coefficients and the statistical accuracy parameters for each model are presented in Table 3. The mean relative percent deviation (P %) values were determined to decide goodness of fit of the models. It was stated in literature that a model is considered to be acceptable if P≤10% (Lomauro et al., 1985). For hot air dried samples, at 25°C, the P value was 8.8% for GAB model and 9.5% for Peleg model. Oswin and Halsey models were also provided good fit to the experimental adsorption data of hot air dried kiwifruit with R^2 ≥0.99, P values less than 10% and RMSE ranging between 0.0129 and 0.0215 at 25°C. At 45°C, all models except Henderson showed similar P values (13.1-14.9%); however higher R^2 and lower RMSE and SSE values were obtained by Peleg model compared to other models. It is seen that, for hot air dried kiwifruit, GAB model provided the best fit to the experimental adsorption data obtained at 25°C while the data obtained at 45°C was best described by four parameter Peleg model. Similar result was obtained for freeze dried kiwifruit. Although both Peleg and GAB models showed good fit to the experimental adsorption data of freeze dried kiwifruit, the lowest P (4.1%) was obtained by GAB model at 25°C while at 45°C, the Peleg model provided similar P(%) but minimum SSE, RMSE and highest R^2 values compared to other models. Similar to our finding, Lim et al. (1995) noted that moisture sorption isotherms of freeze dried blueberries obtained at temperatures between 4-45°C were best described by the GAB equation. However in their study they did not apply the Peleg equation. Among the six equation, the Peleg equation predicted the moisture adsorption isotherms of vacuum dried kiwifruits with smallest P(%), RMSE and highest R^2 values. Peleg model gave P values of 5.6% and 4.8% at 25 and 45°C, respectively. It was stated in literature that, a model with a P value of less than 5% shows an extremely good fit (Lomauro et al., 1985). At 25°C, GAB and Oswin equations correlated the data reasonably well with a P value of nearly 11.5% and 10.9%, respectively. The GAB equation also described the adsorption data well at 45°C. Kaymak-Ertekin and Gedik (2004) obtained adsorption isotherms of grapes, apricots and apples dried in vacuum oven at 70°C. They reported that the sorption data of samples were best described by the Halsey equation at the selected temperatures of 30, 45 and 60°C. They noted that the GAB equation was also suitable for representing the sorption data for all samples and Oswin equation correlate well to the sorption data of apple. In their study they did not evaluate the suitability of Peleg model to describe the sorption data. On the other hand, in another study, Ciurzynska et al. (2012) found the GAB model inapplicable in describing the moisture adsorption behavior of strawberries dried under vacuum with different temperature and pressure combinations. In their study, Peleg and Lewicki models were provided good fit to the experimental data while Halsey did not.

Table 3. Estimated parameters of adsorption isotherm equations

MODEL		HOT AIR DRIED		VACUUM DRIED		FREEZE DRIED	
		25°C	45°C	25°C	45°C	25°C	45°C
GAB	M_0	0.102	0.113	0.137	0.137	0.103	0.142
	K	0.974	0.938	0.928	0.911	0.964	0.914
	C	1.766	1.077	1.196	0.965	2.701	1.034
	SSE	$6.0406*10^{-4}$	0.0012	0.0015	$1.2790*10^{-4}$	$7.3429*10^{-4}$	$6.7697*10^{-4}$
	R^2	0.9993	0.9945	0.9976	0.9992	0.9990	0.9974
	RMSE	0.0113	0.0152	0.0175	0.0060	0.0121	0.0116
	%P	8.8	14.3	11.5	11.3	4.1	6.5
BET	M_0	0.0725	0.0710	0.0641	0.0737	0.0681	0.0784
	C	8.968	3.000	43.710	3.292	26.570	3.619
	SSE	0.0066	0.0020	0.0267	0.0020	0.0144	0.0028
	R^2	0.9925	0.9903	0.9580	0.9911	0.9802	0.9894
	RMSE	0.0331	0.0184	0.0667	0.0184	0.0489	0.0215
	%P	12.1	14.9	24.0	29.1	23.7	16.9
Oswin	C	0.130	0.107	0.149	0.117	0.146	0.126
	n	0.795	0.822	0.689	0.796	0.722	0.789
	SSE	0.0010	0.0014	0.0050	$8.2823*10^{-4}$	0.0012	0.0014
	R^2	0.9988	0.9933	0.9921	0.9964	0.9984	0.9947
	RMSE	0.0129	0.0153	0.0289	0.0117	0.0139	0.0151
	%P	7.5	14.6	10.9	24.7	7.3	13.4
Halsey	C	0.096	0.088	0.100	0.106	0.105	0.104
	n	0.933	0.893	0.933	0.831	0.938	0.881
	SSE	0.0028	0.0173	0.0070	0.0170	0.0109	0.0125
	R^2	0.9948	0.9643	0.9868	0.9651	0.9796	0.9742
	RMSE	0.0215	0.0537	0.0342	0.0532	0.0426	0.0457
	%P	9.0	13.1	15.0	35.5	18.9	23.1
Henderson	C	3.734	4.020	3.630	3.360	3.648	3.401
	n	0.843	0.815	0.850	0.730	0.874	0.773
	SSE	0.0139	0.0245	0.0122	0.0013	0.0085	0.0022
	R^2	0.9739	0.9495	0.9771	0.9973	0.9840	0.9955
	RMSE	0.0481	0.0639	0.0451	0.0147	0.0377	0.0191
	%P	17.6	20.0	16.0	5.4	14.0	6.5
Peleg	C_1	0.323	0.290	0.236	0.328	0.336	0.248
	C_2	1.590	0.784	1.142	0.739	1.354	0.831
	C_3	1.330	1.579	0.942	1.573	1.213	1.177
	C_4	10.480	7.620	7.280	7.640	10.030	6.327
	SSE	0.0011	$4.9714*10^{-4}$	$5.4205*10^{-4}$	$1.2842*10^{-4}$	$8.0367*10^{-4}$	$3.5454*10^{-4}$
	R^2	0.9988	0.9978	0.9991	0.9994	0.9989	0.9986
	RMSE	0.0140	0.0111	0.0116	0.0057	0.0142	0.0094
	%P	9.5	14.6	5.6	4.8	9.4	6.7

In general, Peleg equation was adequate to predict in average the adsorption isotherms with P smaller than 10% for all cases except the isotherm obtained at 45°C for hot air dried kiwifruit. Actually, for this isotherm, all models except Henderson, gave a satisfactory prediction with P value ranging between 13.1-14.9%. The experimental data and their corresponding best fit curves were presented in Figure 1.

Peleg model is an empirical moisture sorption model with four constant which have no physical significance while GAB is a kinetic moisture sorption model. GAB model has greater versatility compared to BET equation and can be used successfully up to high water activities for various dehydrated foods (Al-Muhtaseb et al., 2002). GAB equation was recommended by the European project COST 90 (Wolf et al., 1985). In this study, BET equation gave P values of higher than 12% for all samples. At different temperatures, the adsorption isotherm data of freeze dried blueberries (Lim et al., 1995), hot air dried pear, banana, apple (Mitrevski et al., 2015; Caballero-Ceron et al., 2018) were recorded to be best described by GAB equation. However in these studies suitability of Peleg equation was not tested. M_0 is the GAB monolayer moisture content which is an important parameter for food stability. M_0 values of GAB model were between 10.2 to 14.2 g/100g (d.b.) for dried kiwifruit samples. The GAB monolayer values were higher than the BET values as expected (Timmermann, 2003). GAB monolayer values for kiwifruit were close to those reported by Kaymak-Ertekin and Gedik (2004). Kaymak-Ertekin and Gedik (2004) obtained a satisfactory prediction of adsorption data of grapes, apricots and apples using GAB equation and estimated the GAB parameter M_0 as 11.5, 9.5 and 17.6 g/100g dry solid, respectively. Caballero-Ceron et al. (2018) determined the GAB model parameters for the moisture adsorption data of dried apple, mango and banana at 25, 32 and 40 °C. They reported that the M_0 values decreased with increasing temperature for mango while there was no clear trend for other fruits. In their study, M_0 value increased from 11.8 to 16.6 g/100g dry solid for apple and from 10.8 to 11.3 g/100g dry solid for banana as temperature increased from 25 to 40°C. Similarly, in this study, M_0 value increased slightly as temperature increased from 25 to 45 °C for freeze dried and hot air dried kiwifruit but stayed constant for vacuum dried ones. However, it has been reported by some researchers that, M_0 values predicted by GAB model decreases with increasing temperature for the adsorption isotherms of dried fruits like papaya, mango, pea (Akoy and von Hörsten, 2013; Mitrevski et al.,2015; Vega-Galvez et al., 2008). C and K are the factors related to the heat of adsorption of water in the monolayer and multilayer regions, respectively. The constant K in the GAB model was slightly lower than unity, ranging between 0.91-0.97, for all cases studied as expected (Timmermann, 2003) and the C values ranged between 0.96 and 2.70. These values are consistent with the values given for different foods in the literature (Andrade et al., 2011). The estimated K parameters for kiwifruit was very close to those for hot air dried apple (0.915-0.972), banana (0.947-0.983) and mango (0.907-0.955) determined by Caballero-Ceron et al. (2018). Timmermann (2003) stated that K varies from nearly 0.70 for wheat to about 0.92 for electrolytic systems and higher values of K means a more pronounced upswing seen after the plateau. The highest K was obtained for hot air dried and freeze dried kiwifruit at 25 and 45°C, respectively.

In the water activity range studied, lower equilibrium moisture content values were obtained at 45°C at a given water activity for all dried samples. Caballero-Ceron et al. (2018) obtained adsorption isotherms of dried banana, apple and mango at 25, 32 and 40°C. Similar to our finding, they recorded lower moisture content values in apple when the temperature was increased from 25 to 40°C for the water activity range of 0.11 - 0.90. However they did not detect a clear effect of temperature on the EMC of banana or mango samples. In general, the EMC is expected to be lower at higher temperatures (Al-Muhtaseb et al., 2002; Labuza et al., 1985). However, some researchers have reported the opposite of this trend in foods rich in sugar at high water activity values which results the crossing of isotherm (Mitrevski et al., 2015; Cervenka, 2008; Akoy and Hörsten, 2013; Vega-Galvez et al., 2008). Increased number of adsorption sites due to dissolution of the crystalline sugar at high water activities was given as the cause of this behavior (Ayranci et al., 1990). In this study a crossing point in adsorption isotherm was not detected between aw from 0.11 to 0.87 when the temperature was increased from 25 to 45°C. This finding is in agreement with the finding of Kaya et al. (2010). Kaya et al. (2010) obtained the sorption isotherms of hot air dried kiwifruit slices at temperatures ranging between 25 and 65°C and showed that the EMC values of kiwifruit increased with decreasing temperature within the water activity range of 0.11-1.0.

4. Conclusions

Moisture adsorption isotherms of dried kiwifruit samples were determined at two different temperatures (25 and 45°C) and the experimental data were fitted to six different widely used sorption equations. The adsorption isotherms of dried kiwifruits were very similar in shape and exhibited Type III (J-shaped) behavior according to BET classification. For all cases, lower EMC values were obtained at 45°C at a given water activity. In general, for all samples, the moisture adsorption data fitted well with the Peleg model. Peleg model provided a P value of 14.6% for the hot air dried sample at 45°C and a P value of less than 10% for the rest. However, at 25°C, GAB equation revealed the best fit to adsorption data of hot air dried and freeze dried samples, followed by Oswin equation.

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Conflict of Interest

No conflict of interest was declared by the authors.

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