Original scientific paper
UDC 664.854:634.6

THE DRYING OF KIWI: MODELLING OF DRYING KINETICS AND DESORPTION ISOTHERMS

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Abstract

Dried fruits constitute an alternative to the consumption of fresh fruits and can be consumed during the off-season. In some regions, the production of kiwi fruit oversupplies the fresh consumption and, consequently, the drying process can be used to make processed products. Hence, this work aimed to study the effect of air temperature on the drying kinetics and sorption isotherms of kiwi.

The kiwi samples were obtained from a local market for realization of the experiments. The peel was removed and then the kiwis were cut into slices with 6 mm thickness. Convective drying was performed in an electrical chamber with an air flow rate of 0.5 m/s in the range temperature from 50 to 80 ^{0}C. The drying was carried out until the slices reached a desirable moisture content of about 10% (wet basis). Experimental data were fit to seven mathematical models commonly used to describe the drying kinetics of food products and the performance of the models was compare according to six statistical indicators. To determine the desorption isotherms the water activity was also measured along drying, using a hygrometer, coupled to an isothermal bath. Experimental values were fitted to models available in the literature to describe sorption isotherms.

The results showed that increasing the drying air temperature shortened drying time, so that the drying at 80 ^{0}C allows a reduction of about 71% in the drying time if compared with the temperture of 50 ^{0}C, thus representing an important energy saving. The fitting was evaluated through several indicators commonly used and from the tested kinetic models it was possible to conclude that although the Page, Logarithmic and Wang & Singh models satisfactorily described the drying behaviour of kiwi slices, the best was the Vega & Lemus model. Finally, it was established a nonlinear relation between the Vega & Lemus *k* constant and temperature. When speaking about prediction of sorption isotherms for the dried kiwi slices at different temperatures, the Chen model was confirmed to be very accurate in predicting the equilibrium moisture content at different temperatures. An increase in temperature caused a decrease in the amount of adsorbed water for the same water activity, allowing the kiwi slices to become less hygroscopic at higher temperatures.

Dried kiwi can be used as a functional ingredient in the industry to innovate on its commercialization in diverse processed forms, such as sweets, snacks, breakfast cereals, among other products.

Key words: *Kiwi, Convective drying, Drying kinetics, Thin layer model, Sorption isotherm*.

1. Introduction

Kiwi is a fruit kiwi native to north-central China and the plant genus *Actinidia* contains about 60 species [1]. Is has fuzzy brown skin and flesh with black edible seeds. It is a nutritionally and economically important crop around the world and is described as being rich in fibres, minerals, vitamin C, vitamin E, phenolics and other bioactive compounds [2, 3].

In the last few decades, the production of the fruit oversupplies the fresh kiwi consumption and, consequently, methods of preservation have been used to make processed products, with health benefits [4].

Water is one of the most important components of food and, specially, the free water is closely related to conservation and changes in the chemical, physical, and microbiological characteristics during storage. The most relevant property relative to water in foods is the water activity (a_w), which is defined as the ratio of the vapour pressure of water in the food and the saturation pressure of steam at the same temperature [5].

Drying constitutes an alternative to the consumption of fresh fruits and vegetables and allows their use during the off-season. It is one of the most widely used methods for food preservation, which allows extending their shelf life by removing the water to a level that minimizes the deterioration phenomena due to microorganisms, enzymes or ferments. Furthermore, apart from extending he shelf-life, it also originates smaller space needs for storage and lighter weight for transportation, and more importantly, the avoidance of use of expensive refrigeration systems [6 - 8].

Different drying methods have been used in the drying of fruits and vegetables: solar drying, hot air drying, microwave drying, vacuum drying, spray drying, among others. Air drying is the most commonly used method, despite having some disadvantages, associated with the product quality or energy consumption [8 - 11].

All food materials are characterized by a particular sorption isotherm at a constant temperature. It represents the relationship of the equilibrium moisture content of the food with the relative humidity of its surrounding environment at a particular temperature and provides useful information for food processing operations such as drying, packaging and storage, as well as to predict thermodynamic equilibrium models. When drying, they assume an important role to properly choose the end-point of the process, corresponding to the optimum residual moisture content of the dried food. Such isotherms also give valuable information on how strong the water is bounded to the food matrix, being essential for predicting the drying and rehydration rates [12 - 15].

The present work aimed at determining the drying kinetics for the convective drying of kiwi, as described by empirical models from literature, for different drying temperatures varying from 50 to 80 ^{0}C. Also, desorption isotherms for the drying conditions tested were determined and fit to different models from literature.

2. Materials and Methods

The kiwi samples were obtained from a local market for realization of the experiments. The peel was removed and then the kiwis were cut into slices with 6 mm thickness (Figure 1). For the convective drying, an electrical chamber WTB Binder with ventilation was used, providing an air flow of 300 m^3/h, corresponding to an air flow rate of 0.5 m/s. The chamber was operated at constant temperatures of 50, 60, 70, and 80 ^{0}C, for the drying experiments.

Figure 1. Kiwi slices before drying

The drying was carried out until the slices reached a desirable moisture content of about 10% (wet basis), being therefore the final moisture around or under this limit.

For establishing the drying curves, along drying at every 15 minutes interval random samples were taken to measure the moisture content with a halogen moisture analyser (model HG53, from Mettler Toledo), with operation parameters set at 120 ^{0}C and rate 3 (medium). Table 1 shows the conditions for each drying experiment.

Table 1. Experimental conditions of the different drying temperatures tested

Temperature (^{0}C)	50	60	70	80
Drying time (h:min.)	7:45	5:00	3:30	2:15
Initial moisture (% wet basis)	79.5	79.5	79.5	78.8
Final moisture (% wet basis)	9.7	4.8	9.2	11.9

To determine the desorption isotherms the water activity was also measured along drying, using a hygrometer (Hygroskop BT-RS1, from Rotronic), coupled to an isothermal bath.

2.1 Mathematical modelling

2.1.1 Thin layer models to describe the drying kinetics

Thin layer equations were developed to describe the drying phenomena in a combined way, independently of the mechanism that governs the process. This type of equation has successfully been used to obtain the drying curves for various products allowing determining the drying time. They express the variations in moisture content along the drying process as functions of certain parameters like the drying constant or the lag factor, which are responsible for combined effects of various transport phenomena during drying [16].

Many different thin layer equations can be found in the literature, varying widely in nature, which have been used by many researchers to successfully explain the drying of various agricultural products [17]. Most of the models include a dimensionless variable, the moisture ratio (MR), which includes the moisture content at any moment, W_t, the equilibrium moisture content, W_e, and the initial moisture content, W_0, all expressed on dry basis:

$$MR = \frac{W_t - W_e}{W_0 - W_e} \qquad (1)$$

Table 2 presents some of the most used kinetic models to describe the drying kinetics for the drying of foods.

Table 2. Mathematical models for drying kinetics in foods [7]

Model name	Equation
Page	$MR = \exp(-k\,t^n)$
Modified Page	$MR = \exp[-(k\,t)^n]$
Henderson & Pabis	$MR = a\exp(-k\,t)$
Logarithmic	$MR = a\exp(-k\,t) + c$
Diffusion approach	$MR = a\exp(-k\,t) + (1-a)\exp(-k\,b\,t)$
Wang & Singh	$MR = 1 + a\,t + b\,t^2$
Vega & Lemus	$MR = (a + k\,t)^2$

2.1.2 Modelling of the sorption isotherms

To model the desorption isotherms one of the models used as reference was the GAB model. This model includes three parameters with physical meaning (Weisser, [19]), and is expressed by the equation shown in Table 3, where aw is the water activity, We is the equilibrium moisture content, Wm is the water content of the monolayer, and C and K are temperature dependent functions, related to the energies of interaction between the first and farthest adsorbed molecules in individual sites of adsorption. This analysis was further complemented by fitting the experimental data to other equations found in the literature, as indicated also in Table 3.

2.2 Statistical evaluation

For all treatment of the results the software Sigma Plot V 11.0 was used. For evaluating the appropriateness of the models, some statistical indicators were used [5, 22, and 23], namely the regression coefficient, *R*, together with the MAE, EMSE, SE, SSE and RPD, as highlighted by the following equations:

Mean absolute error:
$$MAE = \frac{1}{N}\sum_{i=1}^{N}\left|V_{\exp,i} - V_{pred,i}\right| \qquad (2)$$

Root mean square error:
$$RMSE = \sqrt{\frac{1}{N}\sum_{i=1}^{N}(V_{\exp,i} - V_{pred,i})^2} \qquad (3)$$

Standard error:
$$SE = \frac{\sqrt{\sum_{i=1}^{N}(V_{\exp,i} - V_{pred,i})^2}}{N-1} \qquad (4)$$

Sum of square errors:
$$SSE = \frac{1}{N}\sum_{i=1}^{N}(V_{\exp,i} - V_{pred,i})^2 \qquad (5)$$

Relative percent deviation:
$$RPD = \frac{100}{N}\sum_{i=1}^{N}\frac{\left|V_{\exp,i} - V_{pred,i}\right|}{V_{\exp,i}} \qquad (6)$$

Table 3. Some models found in literature to describe sorption isotherms [5, 18, 20, and 21]

Model	Equation	Parameters
Non explicit temperature dependent		
GAB		W_m, C , K
Oswin		C , b
Smith	$W_e = A + B\ln(1 - a_w)$	A, B
Chen	$a_w = \exp(-A\exp(-B\,W_e))$	A, B
Explicit temperature dependent		
Model	**Equation**	**Parameters**
Chung & Pfost	$a_w = \exp\left(-\frac{A}{R\,T}\exp(-B\,W_e)\right)$	A, B
Halsey	$a_w = \exp\left(-\frac{A}{R\,T}\frac{1}{(W_e/W_m)^b}\right)$	A, W_m, b
Henderson	1 – aw = exp (– C T Web)	C , b

In the above equations N is the number of observations, while $V_{exp,i}$ and $V_{pred,i}$ are the experimental and predicted values for the dependent variable at any observation i. RMSE aims at comparing the differences between the experimental and predicted values, and when they approach zero it indicates that the prediction is closer to the experimental data. On the other hand, the relative percentage error compares the absolute differences between those values, and for RPD under 10% the fit is considered to be good. RMSE provides information on the short-term performance of the correlations by allowing a term by term comparison of the actual deviation between the calculated value and the measured value [5, 7]. Other statistical information is provided by the correlation coefficient and the standard error of estimate.

3. Results and Discussion

3.1 Experimental drying curves

Figure 2 presents the variations of the dry basis moisture content for the kiwi slices along drying for different temperatures (50, 60, 70 and 80 ^{0}C).

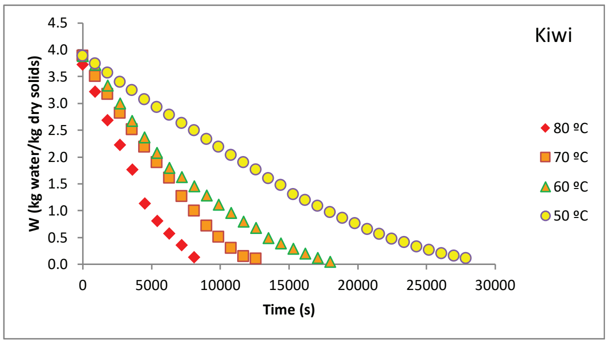

Figure 2. Variation of moisture content of kiwi slices along drying

The initial moisture content of kiwi was 3.88 kg water/kg dry solids or 79.51% (wet basis). The drying curves obtained for the aforementioned temperatures revealed that the moisture content of kiwi slices decreased linearly with time for the first part of the drying process. For higher drying times, however, the decrease in moisture content was slower, thus resembling a characteristic of a falling rate period. The dominant mechanism at the beginning of the drying process was the diffusion (surface diffusion and internal diffusion of water from the inside of the surface).

To reach the equilibrium moisture content, the drying process took 465 min and 135 min, respectively, at temperatures of 50 ^{0}C and 80 ^{0}C. The effect of temperature on the drying process was consistent with other results published in literature for kiwi [24 - 29]. As expected, there was an acceleration of the drying rate due to the increase in thetemperature of the drying air from 50 ^{0}C to 80 ^{0}C. The drying process at 80 ^{0}C allowed a reduction of about 71% of the drying time, as compared with temperature of 50 ^{0}C, representing a very important energy saving. The drying rate reached maximum values at higher temperatures and decreased continously with diminushing moisture content since the migration of water to the surface of the sample and evaporation rate from the surface to the drying air decreased with the fall of moisture in the food.

3.2 Experimental sorption isotherms

The sorption isotherm is useful to determine the shelf life and to assess the background of operations such as drying, conditioning, mixing, packaging, and storage since this will determine the degree of drying required to obtain a stable product. The value of water activity (a_w) for the fresh kiwi was 0.96, which indicates that kiwi had high free water content.

Figure 3 presents the variations of the equilibrium moisture content as a function of a_w, corresponding to the desorption isotherms at different temperatures (50, 60, 70 and 80 ^{0}C). According to the classification of five general types of sorption isotherms proposed by Brunauer *et al.*, [30], the sorption curves obtained for kiwi are of type III isotherms, which is one of the most typical for food systems.
As expected, the equilibrium moisture content increased with water activity at constant temperature.

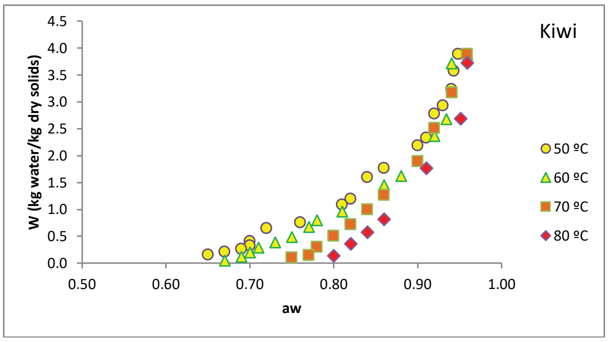

Figure 3. Desoption isotherms for kiwi at different temperatures

A more detailed data analysis lead to the identification of two different regions in the isotherm curves. At low and intermediate water activities, usually known as the multilayer sorption region, moisture content increased linearly with water activity, whereas at high water activity levels, the water content increased sharply with water activity due to capillarity, the so-called capillary condensation region. The moisture sorption isotherm of a food product depends on the hygroscopic properties of its individual components [31]. The effect of temperature on the sorption isotherm is of great importance for prediction of quality and optimization of drying and storage, among others. The equilibrium moisture content revealed an increase in moisture content with decreasing temperature, at constant water activity. This behavior may be attributed to excitation states of molecules. At higher temperatures water molecules are in an increased state of excitation, which allows them to leave their sorption sites of food materials and the links become less stable, thereby decreasing the equilibrium moisture content. This trend indicated that the food became less hygroscopic at higher temperatures as a result of physical and/or chemical changes in the product induced by temperature [32]. The temperature influences the physicochemical properties of foods, which in turn reduces the number of active sites for water binding.

An interesting phenomenon was observed as to the influence of temperature in the equilibrium moisture content. In the so-called capillary condensation region, the equilibrium moisture content was less dependent of temperature than in the multilayer sorption region. At high levels of a_w the binding strength of the water to the solid and between water molecules was weaker than at lower values of a_w, and consequently the rate of evaporation of water from the food was facilitated, even at lower values of temperature. At low moisture content there were highly active polar sites on the surface of the food material, which were covered with water molecules to form the molecular layer and thus the amount of energy required to remove these water molecules, tightly bounded to the food, was very high. Thus, at lower values of moisture content the effect of temperature on the sorption isotherm was more visible than at higher values, for both products.

In addition, the curves had no visible intersection with the increase of temperature. Thus, the sorption isotherm shift due to temperature was mainly explained by changes in water binding, dissociation of water and/or increase of solute solubility in water [33].

3.3 Modelling of the drying kinetics

Due to the lack of information to apply the theoretical models in convective drying process, the semi-empirical models turn out to be a suitable approach to describe the convective drying. Thus, the moisture content data at the different drying air temperatures were converted to the dimensionless variable moisture ratio (MR) and then the experimental data obtained during the drying process at the different drying conditions were fitted using the models presented in Table 2.

The goodness of the fit for each model was evaluated based on the statistical indicators as defined by equations (2) to (6). The parameter's estimation and statistics for the fitting of kinetic drying of kiwi to the different models are presented in Table 4.

Table 4. Parameter estimation and statistics for fitting the kinetic data with mathematical models

Model	Estimation		Temperature			
			50 °C	60 °C	70 °C	80 °C
Page	Parameters	k	9.4779e-7	7.6890e-6	2.2452e-6	4.7813e-6
		n	1.4524	1.3119	1.4852	1.4730
	Statistics	R	0.9972	0.9981	0.9954	0.9979
		MAE	1.9612e-2	1.6602e-2	2.5848e-2	1.6616e-1
		RMSE	2.2592e-2	1.9076e-2	3.0101e-2	1.8131e-1
		SE	4.1226e-3	4.3709e-3	8.3271e-3	6.3707e-2
		SSE	5.1040e-4	3.6389e-4	9.0606e-4	3.2874e-2
		RPD	15.4426	28.1965	25.1872	120.8309
Modified Page	Parameters	k	7.1253e-5	1.2639e-4	1.5730e-4	2.4439e-4
		n	1.4523	1.3119	1.4852	1.4730
	Statistics	R	0.9972	0.9981	0.9954	0.9979
		MAE	1.9612e-2	1.6597e-2	2.5834e-2	1.6082e-2
		RMSE	2.2592e-2	1.9073e-2	3.0084e-2	2.0784e-2
		SE	4.1226e-3	4.3702e-3	8.3225e-3	7.3027e-3
		SSE	5.1040e-4	3.6378e-4	9.0505e-4	4.3197e-4
		RPD	15.4426	28.1957	25.1756	11.1828
Henderson & Pabis	Parameters	k	7.9676e-5	1.4043e-4	1.7395e-4	2.6702e-4
		a	1.0985	1.0838	1.0820	1.0728
	Statistics	R	0.9835	0.9915	0.9795	0.9832
		MAE	4.7843e-2	3.2931e-2	5.6640e-2	5.4121e-2
		RMSE	5.4784e-2	3.9962e-2	6.3326e-2	5.8612e-2
		SE	9.9970e-3	9.1566e-3	1.7519e-2	2.0594e-2
		SSE	3.0013e-3	1.5970e-3	4.0102e-3	3.4354e-3
		RPD	39.9889	54.8191	60.9143	40.6946

Logarithmic	Parameters	k	3.2548e-5	8.7802e-5	6.1516e-5	1.2102e-4
		a	1.7103	1.2915	1.8913	1.6085
		c	-0.6895	-0.2597	-0.8816	-0.5876
	Statistics	R	0.9992	0.9993	0.9989	0.9975
		MAE	1.0318e-2	8.5058e-3	1.2118e-2	2.0357e-2
		RMSE	1.1960e-2	1.1613e-2	1.4552e-2	2.2497e-2
		SE	2.1825e-3	2.6608e-3	4.0257e-3	7.9048e-3
		SSE	1.4305e-4	1.3485e-4	2.1177e-4	5.0613e-4
		RPD	8.1333	4.9440	13.8555	11.3294
Diffusional Approach	Parameters	k	0.0287	0.0384	0.0431	0.0545
		a	-0.1326	-0.1412	-0.1578	-0.2038
		b	2.8698e-3	3.8594e-3	4.3269e-3	5.5153e-3
	Statistics	R	0.9857	0.9945	0.9839	0.9903
		MAE	4.3843e-2	2.6726e-2	4.7808e-2	3.7217e-2
		RMSE	5.0926e-2	3.2198e-2	5.6139e-2	4.4503e-2
		SE	9.2930e-3	7.3776e-3	1.5530e-2	1.5637e-2
		SSE	2.5935e-3	1.0367e-3	3.1516e-3	1.9805e-3
		RPD	37.3649	48.6145	53.6742	30.4945
Wang & Singh	Parameters	a	-5.0749e-5	-9.5139e-5	-1.1026e-4	-1.7722e-4
		b	5.4042e-10	2.2589e-9	2.4177e-9	6.9807e-9
	Statistics	R	0.9993	0.9990	0.9991	0.9979
		MAE	9.9247e-3	9.7847e-3	1.0564e-2	1.8097e-2
		RMSE	1.1058e-2	1.4033e-2	1.2964e-2	2.1043e-2
		SE	2.0179e-3	3.2153e-3	3.5865e-3	7.3937e-3
		SSE	1.2229e-4	1.9692e-4	1.6807e-4	4.4280e-4
		RPD	7.0997	5.4826	12.5007	9.0712
Vega & Lemus	Parameters	k	-2.8711e-5	-4.8348e-5	-6.3308e-5	-9.7583e-5
		a	1.0185	1.0060	1.0167	1.0155
	Statistics	R	0.9984	0.9991	0.9970	0.9976
		MAE	1.4537e-2	1.0218e-2	2.1645e-2	1.8981e-2
		RMSE	1.6870e-2	1.3171e-2	2.4480e-2	2.2114e-2
		SE	3.0784e-3	3.0180e-3	6.7721e-3	7.7700e-3
		SSE	2.8458e-4	1.7349e-4	5.9926e-4	4.8902e-4
		RPD	9.9504	5.4205	19.6172	8.5918

In all cases, the values of the regression coefficient R for the models fitted to the kiwi drying processes at different temperatures were greater than 0.9795, indicating a good fit. However, among the drying models, the Page, Logarithmic, Wang & Singh and Vega & Lemus obtained the best statistical indicators. The values of R, MAE, RMSE, SE, SSE and RPD for these models ranged, respectively, from 0.9970 to 0.9993, 0.0097847 to 0.166616, 0.011058 to 0.030101, 0.0083271 to 0.063707, 0.00017349 to 0.032874 and 4.9440 to 120.8309. However, the best model, with highest values of R and lowest values of RPD, on average, was found to be Vega & Lemus and thus was chosen to represent the thin layer drying of kiwi at the range of temperatures tested, from 50 to 80 ^{0}C.

Figure 4 shows a very good agreement between the experimental and predicted moisture ratio values for kiwi for all the temperatures tested. Hence, this makes clear that Vega & Lemus model could be used to describe the drying behaviour of kiwi slices.

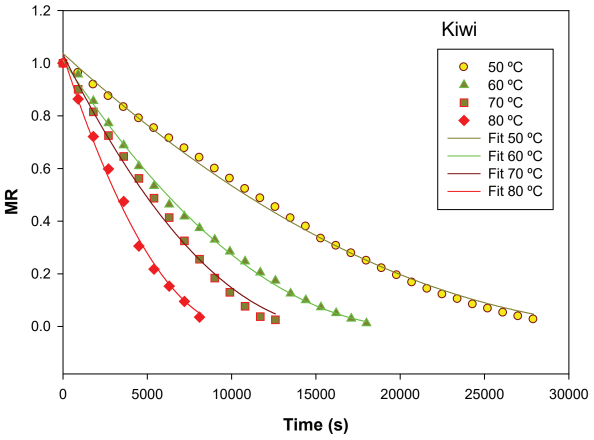

Figure 4. Fitting of the kinetic data to Vega & Lemus model for kiwi at different temperatures

Although the Vega & Lemus model could be used to describe the drying behaviour of kiwi, it does not indicate the effect of the drying air temperature.

The Vega & Lemus model constant *a* (dimensionless) is not dependent on temperature since this value is around 1 for the four temperatures. Within the range of the studied temperatures, the maximum percentage variation of this constant is 1.2%. However, the constant *k* (s^{-1}) is dependent on temperature in the studied range, for both products. Thus, to account for the effect of temperature the constant *k* (s^{-1}) was regressed against air temperature. In this ways, a corrected Vega & Lemus constant was expressed in terms of the drying temperature, T (°C), as:

$$k = -0.000065 + 2.416 \times 10^{-6}\ T - 3.6595 \times 10^{-8}\ T^2 \quad (7)$$

(R = 0.9943)

In summary, Equation (7) can be used to estimate constant *k* (s^{-1}) of kiwi during drying in the temperature range of 50 °C to 80 °C.

3.4 Modelling of the sorption isotherms

The experimental values of equilibrium moisture content as a function of a_w, at different temperatures (50, 60, 70 and 80 °C), were fitted to the sorption isotherm models presented in Table 3. The goodness of fit for each sorption model was evaluated based on statistical indicators like R, MAE, EMSE, SE, SSE and RPD. Table 5 presents the parameters of the models used to fit the experimental data of kiwi as well as the corresponding statistical indicators for each model. Globally, and based on the statistical indicators, the non-explicit temperature dependent models produced a weak robustness to describe the sorption isotherm for kiwi, with exception of the Chen model. In those models, the regression coefficient ranged between 0.9686 and 0.9993, with RPD up to 95.74. The results of the statistical indicators for the other models indicated that they can be considered as acceptable for predicting the equilibrium moisture content of both products. However, Chen and Chung and Pfost models are the best ones to fit the sorption isotherms of kiwi. The goodness of fit can be evaluated by the high values of regression coefficient and low values of RPD (< 2) obtained. For example, the sorption equilibrium moisture isotherms of kiwi using the Chen model for different temperatures are plotted in Figure 5, and it can be observed a good quality of fitting in all range of temperatures.

Table 5. Parameter estimation and statistics for fitting the desorption data with different models

Model	Estimation		Temperature			
			50 °C	60 °C	70 °C	80 °C
GAB (ITD)[1]	Parameters	W_m	1.1549	1.6468	1.7123	0.4786
		C	0.0733	0.0500	0.0344	0.0641
		K	0.9293	0.9249	0.9391	0.9755
	Statistics	R	0.9940	0.9851	0.9853	0.9848
		MAE	1.1901e-1	1.6960e-1	1.8681e-1	1.8673e-1
		RMSE	1.3536e-1	2.1357e-1	2.1070e-1	2.1687e-1
		SE	3.2780e-2	5.9083e-2	6.9882e-2	9.5631e-2
		SSE	1.8324e-2	4.5614e-2	4.4395e-2	4.7033e-2
		RPD	28.8041	67.2723	67.5210	40.6526
Oswin (ITD)[1]	Parameters	C	0.2334	0.2210	0.1715	0.0847
		b	0.9251	0.9490	1.0203	1.1954
	Statistics	R	0.9854	0.9715	0.9686	0.9825
		MAE	1.8189e-1	2.3278e-1	2.7821e-1	1.9275e-1
		RMSE	2.1016e-1	2.9432e-1	3.0623e-1	2.3235e-1
		SE	5.0893e-2	8.1421e-2	1.0157e-1	1.0246e-1
		SSE	4.4169e-2	8.6624e-2	9.3780e-2	5.3986e-2
		RPD	48.0265	95.7423	86.1148	46.6923
Smith (ITD)[1]	Parameters	A	-1.8663	-2.0601	-2.9539	-3.2627
		B	-1.7382	-1.8475	-2.1481	-2.0911
	Statistics	R	0.9915	0.9877	0.9993	0.9892
		MAE	1.2816e-1	1.2433e-1	3.1778e-2	1.1242e-1
		RMSE	1.6063e-1	1.9411e-1	4.4886e-2	1.8332e-1
		SE	3.8898e-2	5.3698e-2	1.4887e-2	8.0835e-2
		SSE	2.5802e-2	3.7677e-2	2.0148e-3	3.3605e-2
		RPD	20.5552	17.5064	11.4555	8.5813

Chen (ITD)[1]	Parameters	A	0.4349	0.4054	0.2902	0.2376
		B	0.7062	0.6512	0.5108	0.5301
	Statistics	R	0.9929	0.9964	0.9984	0.9971
		MAE	9.4860e-3	5.8156e-3	2.8939e-3	3.3333e-3
		RMSE	1.2659e-2	8.2455e-3	3.8759e-3	4.4035e-3
		SE	3.0655e-3	2.2811e-3	1.2855e-3	1.9418e-3
		SSE	1.6025e-4	6.7989e-5	1.5023e-5	1.9391e-5
		RPD	1.1487	0.6877	0.3509	0.3644
Chung & Pfost (ETD)[2]	Parameters	A	180.7801	202.2039	168.8701	158.0481
		B	0.7062	0.6512	0.5108	0.5301
	Statistics	R	0.9929	0.9964	0.9984	0.9971
		MAE	9.4807e-3	5.8222e-3	2.8939e-3	3.3333e-3
		RMSE	1.2655e-2	8.2499e-3	3.8759e-3	4.4035e-3
		SE	3.0646e-3	2.2823e-3	1.2855e-3	1.9418e-3
		SSE	1.6015e-4	6.8062e-5	1.5023e-5	1.9391e-5
		RPD	1.1480	0.6885	0.3509	0.3644
Halsey (ETD)[2]	Parameters	A	69.4252	127.8880	83.1214	75.4956
		W_m	1.0152	0.3702	1.0246	1.0767
		b	0.5035	0.3484	0.3506	0.3872
	Statistics	R	0.9544	0.8945	0.9228	0.9238
		MAE	2.8598e-2	3.9518e-2	2.4806e-2	2.0752e-2
		RMSE	3.1687e-2	4.3549e-2	2.6585e-2	2.2459e-2
		SE	7.6735e-3	1.2048e-2	8.8174e-3	9.9036e-3
		SSE	1.0041e-3	1.8965e-3	7.0679e-4	5.0441e-4
		RPD	3.5679	4.9422	2.9200	2.3797
Henderson (ETD)[2]	Parameters	C	0.0365	0.0299	0.0285	0.0274
		b	0.2986	0.2247	0.1886	0.1909
	Statistics	R	0.9777	0.9340	0.9466	0.9489
		MAE	1.9909e-2	3.1211e-2	2.0888e-2	1.7367e-2
		RMSE	2.2275e-2	3.4802e-2	2.2245e-2	1.8525e-2
		SE	5.3942e-3	9.6276e-3	7.3779e-3	8.1689e-3
		SSE	4.9619e-4	1.2111e-3	4.9485e-4	3.4319e-4
		RPD	2.5218	3.9592	2.4754	2.0005

Legend: [1]ITD = implicit temperature dependence, [2]ETD = explicit temperature dependence.

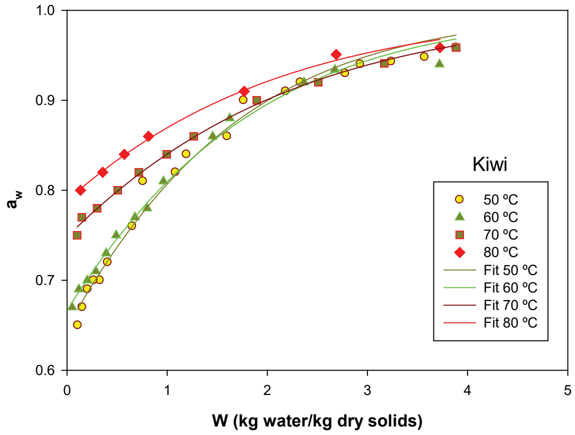

Figure 5. Fitting of the desorption isotherms with model Chen for different temperatures

4. Conclusions

- The present work studied the effect of air temperature (50, 60, 70, and 80 ^{0}C) on the drying kinetics and sorption isotherms of kiwi slices. A non-linear procedure was used to fit semi-empirical models available in the literature and the performance of the models was compared according to six well established statistical indicators. From the results it was concluded that the drying process at 80 ^{0}C represents a very important energy saving since it allows a reduction of about 71% in the drying time, when compared with the temperature of 50 ^{0}C.

- Statistical indicators obtained by fitting the experimental data to the tested kinetic models revealed that the Page, Logarithmic and Wang & Singh models satisfactorily described the drying behaviour of kiwi slices but the best one was the Vega & Lemus model. Furthermore, a non-linear relationship was obtained between the Vega & Lemus *k* constant and temperature.

- According to the BET classification, the moisture sorption isotherms of kiwi can be defined as type III in the temperature range between 50 ^{0}C and 80 ^{0}C. An increase in temperature caused a decrease in the amount of adsorbed water for the same water activity allowing the kiwi slices to be less hygroscopic at higher temperatures. From the comparison between different models, it was possible to conclude that the Chen model was able to provide very good predictions of the sorption isotherms of kiwi at different temperatures.

Acknowledgements

This work is funded by National Funds through the FCT - Foundation for Science and Technology, I.P., within the scope of the project Refª UIDB/00681/2020. Furthermore, we would like to thank the CERNAS Research Centre and the Polytechnic Institute of Viseu for their support.

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