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Research Article

Effect of Temperature on Rehydration of Cornelian Cherry Fruit: A Kinetics Study

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Keywords

Cornelian cherry,
Kinetics,
Drying,
Rehydration,
Activation energy.

Abstract

Cornelian cherry is an important resource for human health and nutrition. Cornelian cherry is very rich in contains many mineral substances such as vitamin C. For this reason, it is important that cornelian cherry can be dried and used later. This was studied investigated the rehydration capacity and the kinetics of dried cornelian cherry fruit under certain conditions. Drying was carried out in a thin layer using a convective dryer. The drying conditions were determined as the different temperatures of air (50, 60, and 70°C) and the constant velocity of air of 1 m/s. The rehydration experiments of dried cornelian cherry were actualized in a hot water bath with a water circulator. The experiments were made with rehydration water temperatures of 25, 50, and 75°C. The rehydration characterization of dried cornelian cherry was evaluated in terms of rehydration curves, rehydration rate curves, final moisture content, and rehydration coefficient (COR). Fick's 2nd law was employed to determine the coefficients of effective diffusivity of the rehydration process. The kinetics models of Peleg, the Weibull, the first-order, and the exponential were used to determine the kinetics of rehydration. The model of Weibull was determined to be the most suitable model for investigating the kinetics of rehydration of cornelian cherry samples. The Model fit was evaluated by considering statistical parameters such as R^2, χ^2, RMSE, and P%. In addition, the energy of activation of rehydration was figured with the rate constants of the most suitable models.

1. Introduction

The Cornaceae family includes Cornus mas L., also known as a cornelian cherry. This species grows naturally in central and southern Europe, southwest Asia, Turkey, China and the Caucasus. Flowers, leaves, and fruits of the cornelian cherry have been traditionally preferred in medicine in various countries of Asia and Europe [1]. Cornelian cherry is remarkable as a natural antioxidant source with its phenolic compounds, anthocyanins, and vitamin C content [2, 3].

Drying is a method that has been used since ancient times to ensure that fruits and vegetables are stored for a longer time and consumed outside of the production season. With the drying process, the content of moisture of the fresh food is decreased and so the formation of microbiological and chemical deterioration is prevented [4, 5]. However, changes in the quality indicators of the foodstuff such as color, shape, appearance, texture, and nutrition occur during the drying process. The point is in both of removal of moisture to produce a dried solid and the development of necessary quality criteria in the dried product. Therefore, it is significant to adjust the processing conditions well to obtain a quality dried product [6].

Oxygen is vital to biological systems. While oxygen is used by cells, reactive oxygen species are formed by many chemical reactions. Oxidative stress occurs as a result of the taking of reactive oxygen species. This state causes many dangerous diseases for example diabetes, cancer, Alzheimer's disease, and heart disease. Antioxidants play an important role in reducing oxidative stress. Recently, there was increasing interest in the use of food containing natural antioxidants such as vitamin C, carotenoids, and phenolic components in human nutrition [7, 8].

Rehydration, which is related to the structural deformation of the drying product, is one of the class indicators of dried food. Many of the dried foodstuffs are consumed after the process of rehydration. The purpose of the process of rehydration is to increase the texture and volume properties of the dried food by contacting it with water and making it suitable for consumption [9]. After the dried food has gained water, the fresh product properties are relatively restored [10]. Rehydration of dried food occurs in three simultaneous stages: the absorption into the dried food of water, the rehydrated products swelling, and the passage of solids into the medium of rehydration. During the rehydration process, while the dried food gains water from the rehydration medium, some soluble components in food (sugar, acid, vitamin and mineral substances, etc.) are transferred to the rehydration medium [10-12]. Some of the factors affecting the rehydration process are the applied drying technique and conditions, the composition of the chemical and structure of physical of the product, the composition of the immersion medium, and the water temperature [13, 14].

Rehydration kinetics is investigated using the models of theoretical and empirical that are based on Fick's second law. Kinetic data provide information about the mechanism of mass transfer to the material and are important for the optimization of the process [15]. The rehydration kinetics of some foods such as quince [14], tomato [16], okra [17], red pepper [15], and naga chili [18] has been studied by various researchers.

In this study, the effect of water temperatures on the rehydration kinetics of dried cornelian cherry fruits at different temperatures was investigated, the effective moisture diffusion coefficients for rehydration were calculated, and the activation energy values for rehydration were determined.

2. Materials and methods

2.1. Raw Material

A fresh supply of cornelian cherries was provided from the Erzurum region. The collected fruits were put in a refrigerator at +4°C to protect them, till used in experiments. The method of the oven was used to investigate the content of initial moisture of fresh fruit [17]. The average content of initial moisture and vitamin C value of fresh fruit were about 75.4±05% (w.b) and 296±0.3 mg/100 g dry matter, respectively.

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2.2. The experimental procedure

An experimental convective dryer was used to dry the materials (Armfield Ltd. Ringwood, England). The drying process was carried out at air temperatures of 50, 60, and 70°C and at the constant velocity of air of 1 m/s. After the dryer was adjusted to the desired operating conditions, it was run empty till reaching steady-state conditions. Fruits (about 350 g) were dispersed in a thin layer on the tray and they were dried from initial moisture content (75.4±0.3% w.b) to final moisture content (8.25±0.65% w.b).

Rehydration experiments of dried cornelian cherry were performed in distilled water environments at 25, 50, and 75°C. The water bath (Memmert, Germany) was adjusted to the rehydration temperature to be studied and then a beaker containing 250 mL of distilled water was placed in the water bath. After the water temperature in the beaker reached the operating temperature, approximately 5 g of dried fruit was added to the beaker. At certain time intervals, the fruits were removed from the water, the surplus water on the fruits was removed with a paper towel, the fruits were weighed with a digital balance with a precision of 0.01 g (AND FX 3000, Japan) and then the fruits were added back to the beaker. Experiments were completed when the change in weight of the samples was not significant. Each experiment was repeated three times.

The content of moisture of the rehydrated sample (X_t), water absorption rate (WAR), and rehydration coefficient (COR) were calculated by Eqs. (1-3) [19-21].

$$X_t = \frac{m_t - m_d}{m_d} \quad (1)$$

$$WAR = \frac{X_{t+\Delta t} - X_t}{\Delta t} \quad (2)$$

$$COR = \frac{m_t(100 - w_f)}{m_d(100 - w_f)} \quad (3)$$

2.3. Effective diffusivity of rehydration

The effective moisture diffusion coefficient (D_{eff}) during rehydration ensures that moisture is transported from the rehydration medium into the food, and Fick's second law is expressed by Eq. (4) [22-26].

$$\frac{\delta M}{\delta t} = D_{eff}\nabla^2 M \quad (4)$$

The analytical solution of Eq. (4) was made by Crank with some assumptions: i) the content of initial moisture in the dehydrated product is constant, ii) during rehydration, the shape of the material is constant and the volume change is neglected, iii) moisture transfer begins with immersion in the rehydration medium, iv) external resistances are neglected and v) diffusivity is constant [22, 27, 28].

$$RR = \frac{X_t - X_e}{X_0 - X_e} = \frac{6}{\pi^2}\sum_{n=1}^{\infty}\frac{1}{n}\exp\left(-\frac{n^2\pi^2 D_{eff}}{{r_{eq}}^2}t\right) \quad (5)$$

For long processing times, only the first term of the series is taken and Eq. (5) is obtained.

$$RR = \frac{X_t - X_e}{X_0 - X_e} = \frac{6}{\pi^2}\exp\left(-\frac{\pi^2 D_{eff}}{{r_{eq}}^2}t\right) \quad (6)$$

Eq. (7) is obtained by linearizing Eq. (6).

$$\ln RR = \ln\frac{6}{\pi^2} - \left(\frac{\pi^2 D_{eff}}{{r_{eq}}^2}t\right) \quad (7)$$

X_e is can be assumed as the final moisture content at end of the rehydration process [21].

Since the fruit has an elliptical shape, the geometric mean diameter was calculated with the following formula [22].

$$D = \sqrt[3]{AxBxC} \quad (8)$$

$$r_{eq} = \frac{D}{2} \quad (9)$$

A, B, and C are the minimum, intermediate, and maximum diameters of dry fruit, respectively.

2.4. Modeling of rehydration kinetics

Models are used to determine time-dependent moisture absorption kinetics during the rehydration of dried samples. To investigate the rehydration kinetics of dried cornelian cherry fruits, four models commonly used in the literature were selected: the kinetic models of Peleg, Weibull, first-order, and the exponential [29-31].

Peleg model:

$$X_t = X_0 + \frac{t}{k_1 + k_2 t} \quad (10)$$

The Peleg model has two parameters as k_1 and k_2. For long enough rehydration times, the equilibrium moisture content is calculated by the following equation [32, 33]:

$$X_e = X_0 + \frac{t}{k_2} \quad (11)$$

Weibull Model:

$$X_t = X_e + (X_0 - X_e)\exp\left[-\left(\frac{t}{\beta}\right)^{\alpha}\right] \quad (12)$$

First order kinetic model:

$$X_t = X_e + (X_0 - X_e)\exp(-Kt) \quad (13)$$

Exponential model:

$$X_t = X_e[1 - \exp(-Ht)] \quad (14)$$

2.5. Calculation of activation energy

The energy of activation (E_a) was determined by Arrhenius' equation. This state represents the relation between the rate constant and temperature.

$$k = k_0 e^{-\frac{Ea}{RT}} \quad (15)$$

2.6. The statistical analysis

Analysis of kinetic parameters was calculated by nonlinear regression analysis method using a software package program at a 95% confidence level (IBM SPSS 20). The coefficient of fit (R^2), chi-square (χ^2), error of square root mean (RMSE) and P% values were used to determine the relationship between models and experimental data. The basic criterion in determining the more suitable model is that the R^2 value is close to 1. In addition, the values of RMSE and χ^2 close to zero and P value less than 10% were considered to have good compatibility.

$$R^2 = 1 - \frac{\sum_{i=1}^{N}(X_{exp,i} - X_{pre,i})^2}{\sum_{i=1}^{N}(X_{exp,i} - X_{pre,i})^2} \quad (16)$$

$$\overline{X_{exp}} = \frac{\sum_{i=1}^{N} X_{exp,i}}{N} \quad (17)$$

$$RMSE = \sqrt{\frac{\sum_{i=1}^{N}(X_{exp,i} - X_{pre,i})^2}{N}} \quad (18)$$

$$\chi^2 = \frac{\sum_{i=1}^{N}(X_{exp,i} - X_{pre,i})^2}{N - z} \quad (19)$$

$$P\% = \frac{100}{N}\sum_{i=1}^{N}\frac{|X_{exp,i} - X_{pre,i}|}{X_{exp,i}} \quad (20)$$

3. Results and discussion

3.1. Effect on drying and rehydration of temperature

The rehydration process is an important method in terms of showing the structural deformation of the material according as the drying method, drying conditions, and pre-treatments applied. The rehydration of convective dried cornelian cherry fruits at 50, 60, and

70°C was investigated in rehydration environments at 25, 50, and 75°C. The rehydration characteristics of cornelian cherry were investigated by considering the rehydration curves, rehydration rate, final moisture content, and COR value.

Figure 1 shows the rehydration curves in terms of moisture ratio (X_t) as a function of time (t). The content of moisture increased with time for all experimental conditions. As given in Figure 1, the increase in drying temperature increased the content of moisture of the fruit. This result indicates that as the drying temperature decreases, there is more structural deterioration in the internal structure of the fruit. It has been reported that low-temperature dried foodstuffs result in a less porous final product with a hydrophilic structure [34, 35].

The moisture amount increased with the increase in rehydration temperature for dried fruits under the like drying conditions. When the rehydration temperature increased from 25°C to 75°C, the moisture content increased from 0.432 to 1.075 for dried fruit at 50°C, from 0.461 to 1.104 for dried fruit at 60°C, and from 0.496 to 1.132 for dried fruit at 70°C. Increasing the water temperature may cause the cell walls to soften more and have a flexible structure.

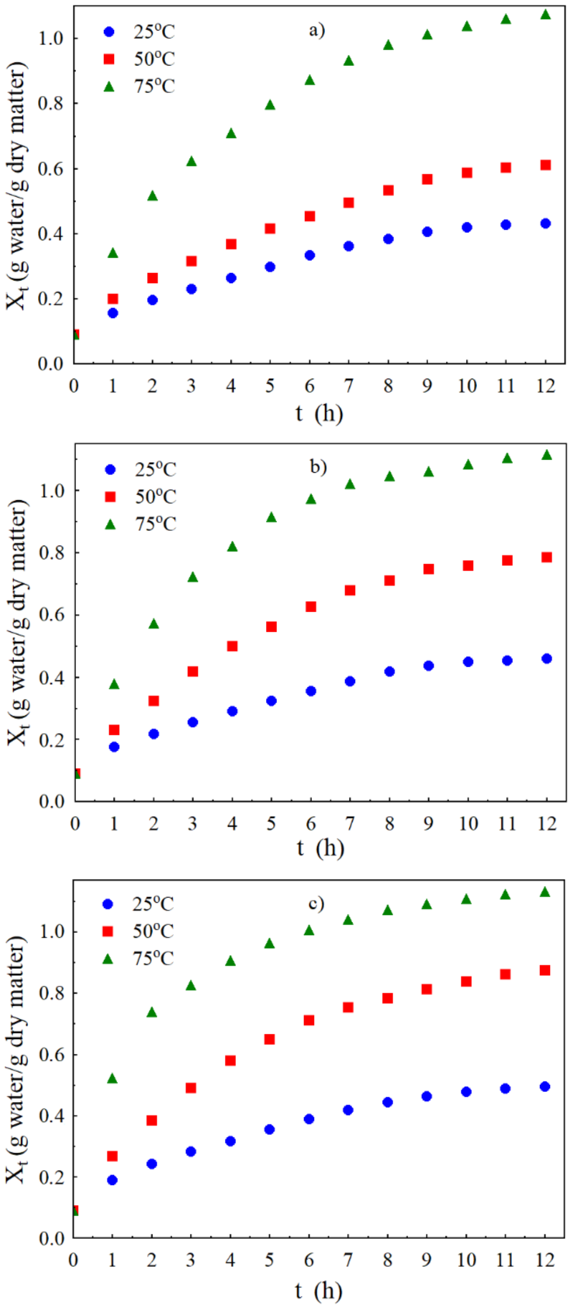

Figure 1. The variation of moisture content (X_t) (a, 50°C; b, 60°C; c, 70°C) with time

Figure 2 gives the variation with time of the rehydration rate. While the rehydration rate was initially high and then it decreased as saturation approached for all of the experimental conditions. In the region where the rehydration rate is high, the water in contact with the surface of the dry fruit quickly is filled the cavities and capillaries in the material close to the surface. With the progression of the rehydration time, the decrease in the number of capillaries and cavities in the fruit leads to a decrease in the rehydration rate. Similar behaviors in rehydration rate have been reported for potato cylinders [36], hawthorn [22], and garlic [19].

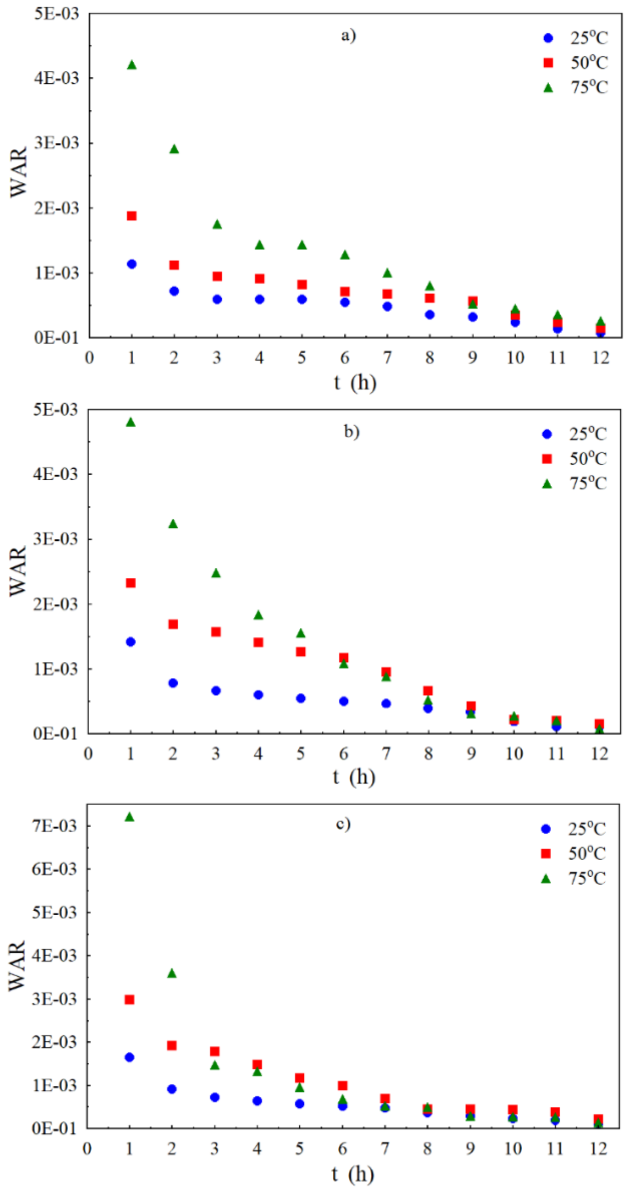

Figure 2. The variation of rehydration rate (WAR) (a, 50°C; b, 60°C; c, 70°C) with time

COR is a measure of the degree of moisture gain of the dried product relative to the fresh product at the end of rehydration. The values of final moisture contents and COR are shown in Table 1. Both final moisture content and COR values increased with increasing rehydration and drying temperature, but the moisture value of fresh fruit (3.06 g water/g d.m) was not reached in any of the experimental conditions. This indicates that an irreversible structural deformation has occurred in the internal structure of the fruit during drying [11].

Table 1. Final moisture content and COR values at the end of the rehydration period for all experimental conditions

Drying temperature °C	Rehydration temperature °C	X_f g water/g dm	COR
	25	0.432	0.367
50	50	0.611	0.413
	75	1.075	0.532
	25	0.461	0.374
60	50	0.785	0.458
	75	1.104	0.542
	25	0.496	0.383
70	50	0.875	0.483
	75	1.132	0.546

3.2. Effective diffusion coefficients

The effective moisture diffusion coefficient expresses the rate of movement of moisture in the dried material during the process of rehydration. The D_{eff} values were calculated from Eq. (7) and the results were given in Table 2. The values of D_{eff} were varied in the range of 3.535x10^{-10} to 3.699x10^{-10} m^2/s for dried fruit at 50°C, in the range of 3.535x10^{-10}-3.699x10^{-10} m^2/s for dried fruit at 60°C and the range of 3.589x10^{-10}-3.849x10^{-10} m^2/s for dried fruit at 70°C for 25-75°C rehydration temperature. The D_{eff} values were varied in the range of 3.535x10^{-10} to 3.617x10^{-10} for 25°C rehydration temperature, in the range of 3.603x10^{-10}-3.767x10^{-10} m^2/s for 50°C rehydration temperature, and in the range of 3.699x10^{-10}-3.931 x10^{-10} m^2/s for 75°C rehydration temperature for 50-70°C drying temperature. These consequences introduce that increasing drying temperature and rehydration temperature increased the values of D_{eff}. This indicates that fruits dried at higher temperatures have a more porous structure and water moves faster through the fruit. The increase in the rehydration temperature in dried fruits under the same conditions increased the D_{eff} value. Increasing the rehydration temperature decreases the viscosity of the water and increases of energy water molecules. These effects allow the moisture to move more easily in the capillaries and cavities in the dried fruit.

Table 2. Effective diffusivity coefficients

Drying temperature (°C)	Rehydration temperature (°C)	D_{eff} x10^{10} (m^2/s)	R²
	25	3.535	0.997
50	50	3.603	0.998
	75	3.699	0.980
	25	3.589	0.995
60	50	3.726	0.990
	75	3.849	0.938
	25	3.617	0.990
70	50	3.767	0.979
	75	3.931	0.901

The D_{eff} values obtained for rehydration of cornelian cherry were in the range of 3.535x10^{-10}-3.931x10^{-10} m^2/s. Similar results were reported for different rehydration temperatures of dried foodstuff such as 1.24x10^{-10}-1.60×10^{-10} m^2/s for mango in the temperature range 25-40°C [28], 2.67-3.67x10^{-10} m^2/s for potato in the temperature range 20-80°C [36] and 8.114x10^{-11}-1.308x10^{-10} m^2/s for quinces in the temperature range 25-70°C [14].

3.3. Modeling of rehydration kinetics

The modelling of rehydration kinetics of cornelian cherry fruit was investigated using four different empirical models the Peleg, the Weibull, the first-order kinetic, and the exponential model. The model coefficients and the statistical parameters of the rehydration models are given in Table 3. The k_1 value in the Peleg model represents the initial moisture absorption rate. k_1 value decreased with increasing rehydration temperature. This trend shows that with increasing rehydration temperature, the absorption ability of water increases [37-38]. When Table 3 is examined, the best fit among the models was obtained in the Weibull model by the highest R^2, and the lowest χ^2, RMSE, and P% values for all experimental conditions. The Weibull model was expressed as the model that best represents the rehydration kinetics of potato cubes [39], quince slices [14], and ginkgo seed slices [20]. The compatibility of the experimental moisture content values with the moisture content values calculated from the Weibull model is shown in Figure 3.

The physical meanings of α and β in the Weibull model provide important information for the rehydration process. α (shape factor) represents the absorption rate of water into the capillaries and cavities near the surface of the material to be rehydrated at the beginning of the rehydration process. The smaller the numerical value of α, the higher the absorption rate at the beginning of the rehydration process. As the value of kinetic constant β decreases, the rate of water uptake of the material increases. In other words, water encounters less resistance as it moves through the solid [40].

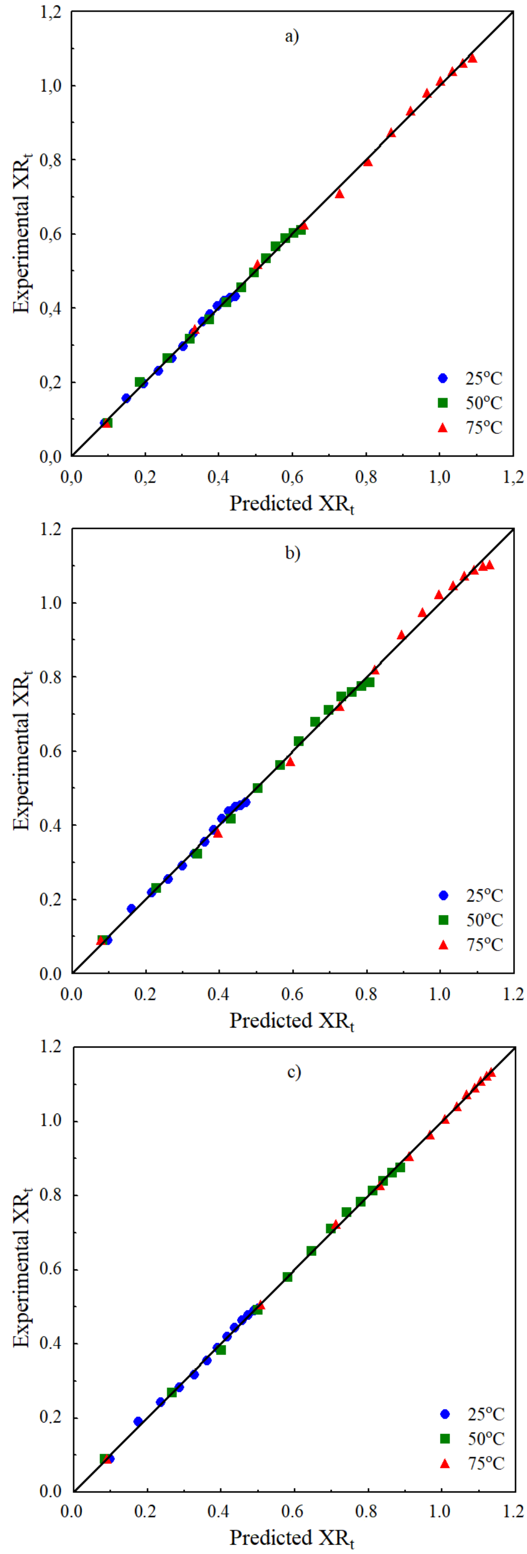

Figure 3. Model fit of theoretical and experimental moisture content (X_t) values according to the Weibull equation

α values decreased with increasing drying temperature and rehydration temperature. When the drying temperature increased from 50°C to 70°C, α values decreased from 1.034 to 0.982 at 25°C rehydration temperature, from 0.885 to 0.819 at 50°C rehydration temperature, and from 0.861 to 0.741 at 75°C rehydration temperature. For the same drying temperature, the increase in the rehydration temperature decreased the α value. When the rehydration temperature increased from 25 to 75°C, the α value decreased from 1.034 to 0.861 for 50°C drying temperature, from 1.092 to 0.986 for 60°C drying temperature, and from 0.982 to 0.741 at 70°C drying temperature. Considering the α values, it can be said that the fruits dried at high temperatures have more porosity in the regions close to the surface.

As shown in Table 3, The variation of β values with drying temperature and rehydration temperature is similar to the variation of α values. In the rehydration process, water absorption takes place from the surface of the fruit to the inside. Therefore, the absorption rate constant β value can be evaluated together with D_{eff} (Table 2). At the same rehydration temperature, with increasing drying temperatures, the β value decreased and the D_{eff} value increased. This result shows that the absorption rate in the fruit increases and the water encounters less internal resistance as it moves through the fruit. In other words, it can be said that the internal structure of the fruits dried at high temperatures is less deformed and has more pore structure [40]. SEM images of gala apple [41] and hawthorn [22] showed that fruits dried at high temperatures were more porous. It is explained that the decrease in drying temperature causes the moisture in the fruit to evaporate more slowly and the drying time increases. A slow evaporation rate causes low internal stress within the fruit. Long drying times and low internal stress lead to the collapse of cell walls.

3.4. Activation energy of rehydration processing

Activation energy values of the rehydration process were calculated using Eq. (15) for three drying temperatures. The absorption rate constant β of the Weibull model, which best fits the kinetic data, was used as the rate constant. A plot of ln of (1/β) versus 1/T(K) is shown in Figure 4. Activation energy values from the slope of the lines obtained for each drying temperature were determined as 10.56 kJ/mol, 15.80 kJ/mol, and 20.75 kJ/mol for 50, 60, and 70°C drying temperatures, respectively. The results are in agreement with the activation energies of previous studies such as 19.2 kJ/mol for mushrooms for the 20-80°C rehydration temperature [29], 14.48 kJ/mol for pretreated quince, and 17.27 kJ/mol for untreated quince at 25-70°C rehydration temperatures [14] and 27.8 kJ/mol for pumpkin slices 30-60°C rehydration temperatures [42].

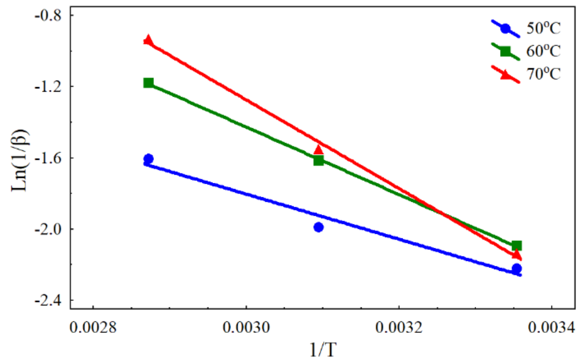

Figure 4. The plot of Ln(1/β) against temperature (1/T) to estimate the activation energy of rehydration

Table 3. Constants and parameters of the models applied for the rehydration

Drying Temperature (°C)	Rehydration temperature (°C)	Model constant							
Peleg		k_1	k_2	X_e	X_0	R^2	χ^2	RMSE	P%
50	25	1.034	1.483	0.766	0.091	0.9981	6.59E-05	0.0070	0.6382
	50	0.885	1.050	1.050	0.097	0.9988	9.11E-05	0.0083	0.7408
	75	0.861	0.720	1.483	0.094	0.9994	1.58E-04	0.0109	1.0044
60	25	1.092	1.517	0.755	0.096	0.9975	9.44E-05	0.0084	0.7874
	50	0.903	0.878	1.220	0.082	0.9982	2.46E-04	0.0136	1.1996
	75	0.986	0.746	1.417	0.077	0.9984	4.21E-04	0.0178	1.6017
70	25	0.982	1.529	0.751	0.098	0.9984	6.69E-05	0.0071	0.6353
	50	0.819	0.860	1.248	0.085	0.9994	1.07E-04	0.0089	0.7372
	75	0.741	0.827	1.299	0.090	0.9999	2.60E-05	0.0044	0.3492
Weibull		α	β	X_e	X_0	R^2	χ^2	RMSE	P%
50	25	1.034	9.227	0.522	0.095	0.9985	5.86E-05	0.0063	0.5792
	50	0.885	7.307	0.833	0.094	0.9988	8.15E-05	0.0074	0.6517
	75	0.861	4.979	1.219	0.092	0.9996	1.21E-04	0.0090	0.7661
60	25	1.092	8.125	0.592	0.094	0.9979	9.13E-05	0.0078	0.7255
	50	0.903	5.026	0.850	0.096	0.9994	8.84E-05	0.0077	0.6763
	75	0.986	3.251	1.138	0.092	0.9999	3.78E-05	0.0050	0.3965
70	25	0.982	8.472	0.652	0.092	0.9989	5.11E-05	0.0058	0.5217
	50	0.819	4.719	0.946	0.092	0.9998	3.15E-05	0.0046	0.3874
	75	0.741	2.538	1.176	0.089	0.9998	6.80E-05	0.0067	0.4593
First Order		K		X_e	X_0	R^2	χ^2	RMSE	P%
50	25	0.130		0.535	0.093	0.9984	5.28E-05	0.0063	0.5829
	50	0.138		0.741	0.102	0.9988	9.20E-05	0.0083	0.7419
	75	0.230		1.139	0.111	0.9989	2.71E-04	0.0143	1.0878
60	25	0.147		0.546	0.099	0.9977	8.83E-05	0.0081	0.7545
	50	0.185		0.885	0.087	0.9992	1.07E-04	0.0090	0.8413
	75	0.309		1.134	0.094	0.9999	3.57E-05	0.0052	0.3867
70	25	0.168		0.560	0.103	0.9981	7.98E-05	0.0077	0.6282
	50	0.215		0.939	0.094	0.9998	2.96E-05	0.0047	0.3875
	75	0.429		1.109	0.118	0.9964	8.69E-04	0.0255	2.3672
Exponential		H		X_e		R^2	χ^2	RMSE	P%
50	25	0.227		0.449		0.9558	1.31E-03	0.0331	2.2047
	50	0.246		0.644		0.9760	1.58E-03	0.0363	2.6069
	75	0.285		1.093		0.9916	1.87E-03	0.0395	2.9658
60	25	0.239		0.471		0.9560	1.47E-03	0.0350	2.4593
	50	0.266		0.833		0.9894	1.17E-03	0.0313	1.8121
	75	0.354		1.115		0.9953	1.13E-03	0.0307	1.8481
70	25	0.270		0.497		0.9604	1.51E-03	0.0355	2.5309
	50	0.287		0.896		0.9917	1.23E-03	0.0320	2.0307

	75	0.503	1.095	0.9894	2.32E-03	0.0440	3.8410

4. Conclusions

This investigation, the effects of drying temperature (50-70°C) and rehydration temperature (25-75°C) on the rehydration of dried cornelian cherry fruits were investigated. In the first stage of the rehydration process, a fast rehydration rate is followed by a slowing rehydration rate. Increasing drying temperature and rehydration water temperature increased the values of D_{eff} and the amount of water absorbed. Both final moisture content and COR values showed that the moisture value of fresh fruit could not be reached. Weibull kinetic model was determined the best model for analyzing the rehydration.

Nomenclature

WAR	g water/g dry matter. time
COR	the rehydration coefficient
m_t	weight of the rehydrate product (g)
m_d	weight of the before rehydration(g)
w_f	moisture content of fresh fruit (%wet basis)
w_r	moisture content of rehydrated fruit (%wet basis)
k	reaction rate constant
t	time (s)
n	reaction order
β	temperature-depend rate constant
α	shape factor
D_{eff}	effective diffusion coefficient (m^2/s)
X_e	equilibrium moisture content (EMC) (kg water/kg dm)
M_f	the final moisture content (kg water/kg dm)
X_t	moisture content at any time (kg water/kg dm)
X_o	the initial moisture content (kg water /kg dm)
r_{req}	r_{eq} radius of dried cornelian cherry (m)
X_0	initial moisture content of before rehydrated (kg water/kg dm)
X_e	content of equilibrium moisture (kg water/kg dm)
k_1	the rate constant of Peleg model (s. kg water/kg dm)
k_2	the capacity constant of Peleg model (kg water/kg dm)
β	velocity parameter of the Weibull model (s)
α	the shape parameter of the Weibull model
K	kinetic constant of first-order model (s^{-1})
H	exponential model is the kinetic constant(s^{-1})
E_a	the activation energy (kJ/mol)
k_0	the pre-exponential factor (h^{-1})
R	universal gas constant (8.314 J/mol K)
T	the absolute temperature (K)
$X_{exp,i}$	i. experimental value for i. experiment
$X_{pre,i}$	i. estimated value for i. experiment
N	number of experimental data
z	model constants

Declaration of Conflict of Interests

The author declares that there is no conflict of interest. They have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

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