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## REHYDRATION KINETICS OF DEHYDRATED BERRIES

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### KEYWORDS

Blueberry, cranberry, diffusivity, mathematical modeling, *Vaccinium* sp.

### ABSTRACT

Cranberries and blueberries are small fruits known for their antioxidant properties. However, due to their high water content and short shelf life, they are generally marketed as dehydrated berries. The present work aimed to model the rehydration of dehydrated berries. Rehydration tests were conducted at 7 and 29°C using milk as a solvent and at 7, 29, and 45°C when the solvent was water. The mass gain was assessed at different intervals, and the experimental data were fitted to the Fick model considering the berries as spheres. Six empirical/semi-empirical models describing the diffusion of water during drying were used to predict the rehydration process. Fick's law satisfactorily represented the data, and the highest diffusion coefficients were found when the berries were rehydrated in water at 45°C. Rehydration of berries in milk resulted in nutrient gain as different diffusive flows occurred during the process. The use of empirical models to predict the operating time of the rehydration processes allows flexibility as such models are mathematically simpler than the Fick model. Diffusivity is essential for the design/construction of equipment, and/or process optimization and implementation.

### INTRODUCTION

The cranberry is a false berry with an intense red color and a very pronounced acid taste. In 2018, the annual global cranberry production surpassed 722 thousand tons, of which the American continents were responsible for more than 95%, and the USA, Canada, and Chile were the leading producers of this fruit. The blueberry has a characteristic bittersweet taste, a bluish-purple color, and many seeds in its interior. In 2018, more than 680 thousand tons of blueberries were produced worldwide, and Canada was the major producer (FAOSTAT, 2020).

Berry fruits, such as cranberries, bilberries, lowbush blueberries, and blueberries, are rich sources of bioactive compounds, mostly polyphenolics, as well as polysaccharides, carotenoids, ascorbic acid, and others (Gramza-Michałowska et al., 2017). Numerous health-promoting properties of berries have been identified, such as in reduction of cancer, cardiovascular and neurological diseases as well as anti-inflammatory, antibacterial, anti-allergic, anti-hypertensive, antiviral and wound-healing effects (Ballesteros et al., 2017; Alvarez-Suarez et al., 2016). Phenolic compounds, present in many fruits and

vegetables, have been studied extensively for their high antioxidant power because they are capable of increasing resistance to oxidative damage caused by free radicals generated in the human body (Ho et al., 2020).

Although they are beneficial to health, most berries, such as cranberries, blueberries, and raspberries, are traditionally grown in areas with cold climates, such as swamps and coniferous forests (Oszmiański et al., 2015), and must therefore be harvested during a specific period, which is one of the factors limiting their consumption. The climate over most of Brazil is typical of a tropical country, which limits the harvest of these fruits to the southern region, restricting their production and consumption (Silveira et al., 2007).

The high moisture content of berries is also a limiting factor in their storage shelf life, which is only a few days. Some preservation methods, such as drying, have been used to increase the shelf life and the possibility of continuous commercialization of food products. Drying increases the shelf life of a dehydrated product, as it reduces its water activity, stabilizing/decreasing the microbiological, biochemical, and chemical activity. Dehydration also reduces the cost of transportation and

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storage, due to the weightlessness and compactness it imparts. The dehydration process must guarantee adequate moisture in the dry product for better conservation of the fruit, thus guaranteeing its quality (Rudy et al., 2015; Krokida & Marinou-Kouris, 2003; Lewicki, 1998).

The preservation of fruits, vegetables, and similar products by dehydration is a major challenge because moisture removal must be carried out so as to minimize damage, thus guaranteeing product quality. In this way, the characteristics of the dehydrated product following rehydration are as close as possible to those of the natural product (Demiray & Tulek, 2017).

To recover the properties of the fresh product, the dehydrated fruit goes through a complex process of rehydration, which can be considered as a measure of the damage caused by the drying processes and dehydration treatments (Lee et al., 2006). Rehydration is divided into three stages: soaking the dried fruit, swelling the rehydrated fruit, and leaching the soluble compounds. Its purpose is to obtain products that, when reconstituted, present the characteristics of texture and increased volume that render them suitable for consumption (Gökçe Kocabay & İsmail, 2017; Lee et al., 2006). According to Lee et al. (2006), after the water has filled all the pores, the properties of the fresh product are partially restored.

The study of food rehydration kinetics enables the design of equipment and the optimization of the rehydration process because it considers the speed of water absorption and how it will be affected by variations in processing, indicating how the saturation time can be predicted. Rehydration data provide information on the water transport mechanism used to determine the water diffusion coefficient in products (Demiray & Tulek, 2017).

Considering the nutritional value of berries, their unique taste and color, and their use in bakery products, while aiming to obtain the necessary data for construction/improvement of equipment and optimization of implemented processes, the present work studied the rehydration kinetics of dehydrated cranberries and blueberries.

## MATERIAL AND METHODS

### Raw materials and physicochemical analysis

Dehydrated cranberries and blueberries were purchased from a market specializing in natural products in the cities of Medianeira and Foz de Iguçu, state of Paraná, Brazil, in February and September 2016, respectively.

Analyses of moisture content, protein, ash, and water activity were performed in triplicate on dehydrated berries and fruits rehydrated in water and milk, for 45 minutes at room temperature. The operating temperature was selected to produce the lowest energy expenditure. The choice of rehydration time was based on the percent water gained by the berries during rehydration, so that the rehydrated fruit would have similar characteristics to those of fresh ones in the shortest possible processing time. After 45 minutes of processing, the berries showed a mass gain of more than 40%, mainly due to water absorption.

The moisture content of the samples was determined gravimetrically in an oven at 105°C until they reached a constant weight, and the ash content was determined in a

muffle furnace at 550°C until a white residue was obtained, both according to the methodology proposed by the Association of Official Analytical Chemists (AOAC, 2005). To determine the protein content, the Kjeldhal method was used, with eight hours of digestion, using 6 g of catalytic mixture to which was added 25 mL of concentrated sulfuric acid and 5 g of sample. For distillation, boric acid, mixed indicator, and 50% sodium hydroxide were used to neutralize the sample. For titration, 0.1N hydrochloric acid was used, and the correction factor for calculating the total protein content was 6.25 (AOAC, 2005). Water activity was determined using Aqualab equipment (AquaLab 4TE, São José dos Campos, SP, Brazil).

### Rehydration kinetics

Berries were rehydrated according to a methodology adapted from Demiray & Tulek (2017) and Falade & Abbo (2007), in triplicate, in beakers, using a 1:40 ratio of sample to solvent (water or milk).

Rehydration experiments using milk were carried out at a temperature of 7°C ± 3°C, in a domestic refrigerator (Brastemp Frost Free Duplex, Medianeira, PR, Brazil), and at room temperature (29°C ± 1°C). Rehydration experiments using water, besides these two temperatures, were also carried out at 45°C ± 1°C. Experiments performed at temperatures of 29 and 45°C were carried out in BOD incubator chambers (BOD, Cienlab, Campinas, SP, Brazil).

Samples were weighed during rehydration at regular intervals for 30 h. Fruits were carefully removed from the beaker with a lab spatula and gently dried with absorbent paper before weighing. Due to the weighing procedure, after 16 h of rehydration, it was found that the fruits started to lose small pieces during weighing, resulting in a mass loss. Thus, the mass gain data for the berries were considered for up to 16 h of processing. Therefore, the equilibrium data were obtained dynamically after 16 h of rehydration.

### Mathematical modeling

The experimental data for mass gain were fitted to Fick's law (Equation 1) considering berries as spheres and inserting sphericity into the equation (Equation 2), as proposed by Falade & Abbo (2007) and Hebbbar & Rastogi (2001).

$$\frac{dx}{dt} = D_{eff} \frac{\partial^2 x}{\partial z^2} \quad (1)$$

in which:

$X$  represents moisture, on a dry basis;

$t$ , time, in s;

$z$  is the characteristic dimension, which depends on the shape of the solid, in m,

$D_{eff}$  represents the effective diffusion coefficient during the rehydration of the solid, in m<sup>2</sup> s<sup>-1</sup>.

For long drying periods, and in this case for rehydration, the series represented by [eq. (2)] converges quickly. Thus, it is possible to calculate the diffusion coefficient graphically from the linearization of the first term of the series represented by [eq. (3)], as proposed by Ismail et al. (2017) when evaluating sun drying of green

bean and similarly to that proposed by Aral & Beşe (2016) when evaluating the drying kinetics of hawthorn fruit.

$$RX = \frac{\overline{X}_t - X_{eq}}{X_0 - X_{eq}} = \frac{6}{\pi^2} \sum_{n=1}^{\infty} \frac{1}{n^2} e^{\left(\frac{-n^2 \pi^2 D_{ef} t}{\psi^2 R_{eq}^2}\right)} \quad (2)$$

$$RX = \frac{6}{\pi^2} e^{\left(\frac{-\pi^2 D_{ef} t}{\psi^2 R_{eq}^2}\right)} \quad (3)$$

in which:

$RX$  represents the moisture ratio, dimensionless;

$\overline{X}_t$  is the instantaneous moisture content, in each time interval, on a dry basis (d.b.);

$X_{eq}$  is the equilibrium moisture content after a certain drying/rehydration time, in d.b.;

$X_0$  is the initial moisture of the solid, in d.b.;

$R_{eq}$  is the equivalent radius, calculated according to Falade & Abbo (2007) and Hebbar & Rastogi (2001), in cm;

$\psi$  is the sphericity;

$t$  is time, in s,

$D_{ef}$  is the effective diffusion coefficient of water during the rehydration of the berries, in  $\text{cm}^2 \text{s}^{-1}$ .

The equivalent radius was calculated according to Falade & Abbo (2007) and Hebbar & Rastogi (2001) as follows:

$$R_s = \frac{3V}{S_p} = \left(\frac{3V}{S_s}\right) \left(\frac{S_s}{S_p}\right) = \psi R_{eq} \quad (4)$$

$$V = \left(\frac{4}{3}\right) \pi a^2 b \quad (5)$$

$$S_p = 2\pi a^2 + \left(\frac{\pi b^2}{e}\right) \ln\left(\frac{1+e}{1-e}\right) \quad (6)$$

$$e = \left[1 - \left(\frac{b}{a}\right)^2\right]^{1/2} \quad (7)$$

$$\psi = \left(\frac{S_s}{S_p}\right) \quad (8)$$

in which:

$V$  and  $S_p$  are the volume and the surface area of the berries, respectively;

$S_s$  is the surface area of a sphere with a volume equal to that of the sample;

$\psi$  is the shape factor,

$R_s$  is the radius of the sphere;

$R_{eq}$  is the equivalent radius of the berries;

$a$  and  $b$  are, respectively, major and minor semi-axes of the rotating ellipse,

$e$  is eccentricity.

Six empirical and semi-empirical models used to describe drying operations were tested, in addition to Fick's law, to describe the rehydration of berries. Therefore, it was considered that, in both operations, mass transfer occurs by diffusion of water inside the fruits. These models are shown in Table 1.

TABLE 1. Mathematical models used to predict food rehydration.

Model	
Verma	$RX = ae^{-kt} + (1-a)e^{-k_1t}$ (9)
Page	$RX = e^{-kt^n}$ (10)
Newton	$RX = e^{-kt}$ (11)
Henderson and Pabis	$RX = ae^{-kt}$ (12)
Two-term exponential	$RX = ae^{-kt} + (1-a)e^{-kat}$ (13)
Diffusion approximation model	$RX = ae^{-kt} + (1-a)e^{-kbt}$ (14)

Where:  $RX$  is the moisture ratio, dimensionless;  $k, k_1$  are drying constants, in  $\text{t}^{-1}$ ;  $a, b, c, n$  are coefficients of the models, dimensionless;  $t$  is the drying time, in s;  $D_{ef}$  is the effective diffusion coefficient of water or milk during the rehydration of berries, in  $\text{cm}^2 \text{s}^{-1}$ .

Source: Adapted from Aral & Beşe (2016).

### Statistical assessments

To test for significant differences among the physicochemical characteristics assessed, analysis of variance (ANOVA) and Tukey's test at the 5% level of significance were performed.

The parameters of the rehydration models (Eqs. 9 to 14) were obtained by non-linear regression using a statistical software program that uses the least-squares method (Gauss-Newton) to fit the experimental data, using a convergence criterion of  $1 \cdot 10^{-6}$ . Fick's law was fitted to the experimental data through the linearization of Eq. 3.

To verify the fit of the experimental data to the models, the magnitude of the coefficient of determination ( $R^2$ ), the root mean square error ( $RMSE$ ), and the values of the relative mean error ( $P$ ) were assessed, the latter calculated according to eqs (15) and (16), respectively.

$$RMSE = \sqrt{\frac{\sum_{i=1}^N (x_{calc} - x_{exp})^2}{n}} \quad (15)$$

$$P = \frac{100}{n} \sum_{i=1}^N \frac{|x_{exp} - x_{calc}|}{x_{exp}} \quad (16)$$

in which:

$x_{exp}$  is the experimental value;

$x_{calc}$  is the value predicted by the model,

$n$  is the number of experimental observations.

According to Rudy et al. (2015), low values of  $RMSE$  and  $R^2$  close to 1.0 denote a good fit of the experimental data to the models. According to Krokida & Marinou-Kouris (2003), the relative mean error indicates the relative error of the predictions, and values below 10% are indicative of a reasonable fit for more practical purposes.

## RESULTS AND DISCUSSION

### Physicochemical characteristics of the berries

Table 2 shows the physicochemical characteristics of the berries before and after rehydration at 29°C for 45 min.

TABLE 2. Physicochemical characteristics of dehydrated and rehydrated berries in water and milk at 29°C for 45 min.

	Moisture (%)	Ash (%)	<i>aw</i>	Proteins (%)
<b>Cranberries</b>				
Dehydrated	19.98 ± 0.40 <sup>a</sup>	0.24 ± 0.03 <sup>a</sup>	0.5962 ± 0.0174 <sup>a</sup>	0.37 ± 0.04 <sup>a</sup>
Rehydrated in water	29.20 ± 0.87 <sup>a</sup>	0.21 ± 0.02 <sup>a,b</sup>	0.9050 ± 0.0322 <sup>b</sup>	0.31 ± 0.10 <sup>a</sup>
Rehydrated in milk	26.33 ± 0.27 <sup>a</sup>	0.29 ± 0.01 <sup>a,b</sup>	0.8251 ± 0.0850 <sup>b</sup>	0.65 ± 0.1 <sup>b</sup>
<b>Blueberries</b>				
Dehydrated	16.78 ± 0.45 <sup>c</sup>	0.23 ± 0.03 <sup>b</sup>	0.6072 ± 0.0089 <sup>b</sup>	1.84 ± 0.32 <sup>b</sup>
Rehydrated in water	47.33 ± 0.09 <sup>a</sup>	0.12 ± 0.04 <sup>b</sup>	0.9678 ± 0.0090 <sup>a</sup>	1.56 ± 0.15 <sup>b</sup>
Rehydrated in milk	35.24 ± 0.95 <sup>b</sup>	0.59 ± 0.16 <sup>a</sup>	0.9373 ± 0.0240 <sup>a</sup>	2.64 ± 0.07 <sup>a</sup>

Results expressed as average ± standard error. Lowercase letters superscript in the same column for the same fruit indicate a statistical difference according to Tukey's test ( $p < 0.05$ ).

Moisture and water activity of the dehydrated berries showed reduced values, which was expected because they were subjected to the drying operation.

The ash content of dehydrated berries was similar to that found in blueberries by Silveira et al. (2007):  $0.19 \pm 0.01\%$ . On the other hand, the protein content was lower than that verified by the authors ( $0.57 \pm 0.04\%$ ). Furthermore, the protein content of the blueberries used in rehydration tests was much higher than that of cranberries and blueberries assessed by Silveira et al. (2007).

After rehydration, there was a significant increase in the moisture and water activity of the fruits, as expected. Also, it was found that the protein and ash contents of the fruits rehydrated in milk were significantly higher than those determined in dehydrated fruits and those rehydrated

in water, indicating the diffusion of other compounds present in milk, such as minerals and amino acids, into the fruit. The berries rehydrated in water, on the other hand, showed a reduction in the abovementioned contents, albeit nonsignificant, possibly due to leaching from the fruits during rehydration as a result of diffusion of the components present in the cellular tissue of the berries into the water.

### Diffusion coefficients

The diffusion coefficients of water and milk during the rehydration of blueberries and cranberries, calculated from the linearization of Eq. 3, and the statistical parameters used to verify the fit of the experimental data to Fick's law are shown in Table 3.

TABLE 3. Diffusion coefficients of water and milk during the rehydration of berries at different temperatures and statistical parameters used to assess the fit of experimental data to the model.

	<i>T</i> (°C)	<i>D<sub>ef</sub></i> (cm <sup>2</sup> s <sup>-1</sup> )	<i>R</i> <sup>2</sup>	<i>P</i> (%)	<i>RMSE</i>
<b><i>Cranberries</i></b>					
<b>Water</b>	7	8.33·10 <sup>-5</sup> ± 7.70·10 <sup>-6</sup> b	0.94	23.49	0.24
	29	9.35·10 <sup>-5</sup> ± 1.63·10 <sup>-5</sup> b	0.96	23.26	0.24
	45	1.25·10 <sup>-4</sup> ± 2.23·10 <sup>-5</sup> a	0.96	20.87	0.23
<b>Milk</b>	7	1.21·10 <sup>-4</sup> ± 8.42·10 <sup>-6</sup> a	0.92	23.19	0.24
	29	1.50·10 <sup>-4</sup> ± 3.39·10 <sup>-5</sup> a	0.97	20.00	0.23
<b><i>Blueberries</i></b>					
<b>Water</b>	7	3.08·10 <sup>-8</sup> ± 3.97·10 <sup>-9</sup> a	0.93	38.54	0.33
	29	3.57·10 <sup>-8</sup> ± 2.78·10 <sup>-9</sup> a	0.85	38.83	0.32
	45	3.64·10 <sup>-8</sup> ± 1.08·10 <sup>-9</sup> a	0.83	41.06	0.32
<b>Milk</b>	7	3.65·10 <sup>-8</sup> ± 3.79·10 <sup>-9</sup> a	0.75	41.25	0.33
	29	2.51·10 <sup>-8</sup> ± 8.86·10 <sup>-10</sup> b	0.84	38.2	0.3

Results are expressed as mean ± standard error. Lowercase superscript letters in the same column for the same fruit indicate a statistically significant difference according to Tukey's test ( $p < 0.05$ ).

The diffusion of both water and milk was influenced by temperature, increasing as temperature increased. During the rehydration of cranberries in water, there was no significant difference between the diffusion coefficients at 7 and 29°C. However, they were both significantly lower than the diffusion coefficient at 45°C. In milk, there was an increase in the value of diffusivity with temperature, although the difference was not significant. At the lowest process temperature, the diffusion coefficients in milk were greater than those in water. However, at 29°C, the diffusivities of water were greater than those of milk. This observation requires further confirmation. However, as verified in the analysis of the ash and protein contents, when the fruit was rehydrated with milk, not only water but also other nutrients diffused into the fruit, and these different diffusive flows may have influenced, positively or not, the diffusion of the solvent (milk).

It was found that Fick's law reasonably fit the experimental data, as the coefficient of determinations ( $R^2$ ) were greater than 0.75, the  $P$  values greater than 10%, and the  $RMSE$  was close to zero.

Falade & Abbo (2007), when assessing the dependence of the effective diffusion coefficient on temperature during drying and rehydration of three different date cultivars, found that the effective diffusion coefficients ( $D_{ef}$ ) ranged from  $1.8 \cdot 10^{-10}$  to  $1.15 \cdot 10^{-9}$  m<sup>2</sup> s<sup>-1</sup> (soft red),  $2.69 \cdot 10^{-10}$  to  $9.51 \cdot 10^{-10}$  m<sup>2</sup> s<sup>-1</sup> (Time 2), and  $4.27 \cdot 10^{-10}$  to  $1.41 \cdot 10^{-9}$  m<sup>2</sup> s<sup>-1</sup> (Time 3) when the water rehydration process was carried out in the temperature range between 15 and 45°C. The authors observed an increase in the effective diffusion coefficient with increasing process temperature, as seen in the present study. The diffusivities calculated by Falade & Abbo (2007) were lower than those determined in the present work. However, it must be considered that those authors dehydrated the fruits themselves, controlling the process parameters properly. In the present study, the fruits

were purchased from a local market and they had already been dried.

#### Modeling of rehydration from empirical/ semi-empirical models

For the rehydration of cranberries in water, the fit to all the tested empirical or semi-empirical models showed high correlation coefficients,  $R^2 > 0.95$ ,  $P$  values below 10%, and low  $RMSE$  values, which indicates a good data fit. On the other hand, the fit of the experimental data for the rehydration of dehydrated blueberries in water to the proposed models was less than ideal since the  $R^2$  values were less than 0.90 and the  $P$  values greater than 10%.

For the rehydration of cranberries in water at 7°C, the Page model ( $RX = e^{-0.0022t^{0.7588}}$ ) was the one that best fit the experimental data because it presented  $R^2 = 0.98$  and the lowest values of  $P$  and  $RMSE$ . At 29°C, the diffusion approximation model [ $RX = -0.0153 e^{-0.5222t} + (1 + 0.0153) e^{-0.0006t}$ ] was the one that best represented the experimental data, as it presented the highest correlation coefficients ( $R^2 = 0.99$ ) and the lowest values of  $P$  and  $RMSE$ . For the experiments carried out in the water at 45°C, the Verma [ $RX = 0.9996 e^{-0.0009t} + (1 - 0.9996) e^{0.0134t}$ ] and diffusion approximation [ $RX = 0.9997 e^{-0.0009t} + (1 - 0.9997) e^{0.0134t}$ ] models presented the best fit, with  $R^2$  values equal to 0.99 and  $P$  less than 1%.

For the rehydration of blueberries in water, the diffusion approximation model was the one that best represented the experimental data at temperatures of 7°C

[  $RX = 0.9706 e^{-0.0021t} + (1-0.9706) e^{0.0057t}$  ] and  
 29°C [  $RX = 0.9981 e^{-0.0022t} + (1-0.99817) e^{0.0139t}$  ],  
 presenting  $R^2 > 0.96$ ,  $P$  values below 4%, and  $RMSE$  close  
 to zero. For the experiment conducted at 45°C, the  
 experimental data showed the best fit to the Verma  
 [  $RX = 0.0437 e^{0.0060t} + (1-0.0437) e^{-0.0033t}$  ] and  
 diffusion approximation  
 [  $RX = 0.9563 e^{-0.0033t} + (1-0.9563) e^{0.0060t}$  ] models,  
 with the highest values of the coefficient of determination  
 and the lowest of  $P$  and  $RMSE$ .

In the rehydration tests of cranberries in milk, it was  
 found that all models had correlation coefficients ( $R^2$ )  
 greater than 0.90,  $P$  values lower than 10%, and low  $RMSE$   
 values, indicating a good fit to the experimental data. The  
 same was not observed for the rehydration of blueberries in  
 milk, as some models had  $R^2$  less than 0.90 and  $P$  values  
 greater than 10%.

For the temperature of 7°C, the diffusion  
 approximation model  
 [  $RX = -0.0427 e^{-0.2445t} + (1-0.0427) e^{-0.0005t}$  ] was  
 the one that best represented the experimental data of  
 rehydration of cranberries in milk, with  $R^2 = 0.99$  and low  
 values of  $P$  and  $RMSE$ . At 29 °C, experimental data on  
 rehydration in milk were a better fit to the Verma model  
 [  $RX = -6.6195 e^{0.0006t} + (1+6.6195) e^{0.0004t}$  ], due  
 to presenting the highest correlation coefficient ( $R^2 = 0.99$ )  
 and the lowest  $P$  and  $RMSE$  values. The rehydration of  
 blueberries at a refrigerated temperature was best  
 represented by the Page model ( $RX = e^{-0.0130t^{0.6499}}$ )  
 because the  $P$  and  $RMSE$  values were the lowest among all  
 the models considered, even though the value of the  
 coefficient of determination was lower than 0.90 ( $R^2 =$   
 0.88). At 29°C, the experimental data on the rehydration of  
 blueberries in milk were a better fit to the Verma model [  $RX = 0.0265 e^{-0.7223t} + (1-0.0265) e^{-0.0011t}$  ], with  $R^2$   
 = 0.99,  $P = 1.76$  % and  $RMSE = 0.02$ .

No studies on the rehydration of dehydrated foods  
 using empirical and semi-empirical models to describe the  
 rehydration process, as performed in the present study, were  
 found in the literature. However, considering the  
 phenomenon of mass transfer by diffusion, the modeling  
 mentioned above was considered relevant. Therefore, it was  
 not possible to compare the fit of the rehydration data to  
 the empirical/semi-empirical models with other works in  
 the literature.

However, Rudy et al. (2015) used the Newton, Page,  
 Henderson and Pabis, logarithmic, Wang and Singh, and  
 two-term exponential models to represent the drying  
 kinetics of cranberries. They found that the drying data for  
 whole fruits were a better fit to the logarithmic model and  
 that the models by Wang and Singh and Page were the ones  
 that best represented the drying data for fruit pulp.

It is also important to emphasize that these are  
 empirical models used to predict the moisture content of the  
 samples in a certain period. However, the models presented  
 in Table 1 do not provide information related to the  
 diffusion of the species.

## CONCLUSIONS

Rehydration presented itself as a promising  
 alternative for the enrichment of dehydrated foods when  
 solvents rich in nutrients are used in the process as the  
 rehydration of berries in milk resulted in nutrient gains as a  
 consequence of the different diffusive flows that occur  
 during the process. In this sense, the authors believe that  
 additional studies should be conducted on rehydration using  
 milk to investigate the diffusion of not only water but also  
 other nutrients from milk to fruits. Fick's law satisfactorily  
 represented the rehydration of dehydrated fruits, making it  
 possible to calculate the diffusion coefficients of water and  
 milk. These data are essential for the design/construction of  
 equipment, and/or the optimization and implementation of  
 processes. The rehydration of dehydrated cranberries and  
 blueberries showed a good fit to the empirical/semi-  
 empirical models usually used to describe food drying.  
 These data are of interest as the calculation of the operating  
 time can be performed based on the abovementioned  
 models, which enable flexibility as they are mathematically  
 simpler than Fick's law.

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