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Kinetics and thermodynamic properties related to the drying of 'Cabacinha' pepper fruits

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Key words:
Capsicum chinense L.
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ABSTRACT

The objective of this study was to determine and model the drying kinetics of 'Cabacinha' pepper fruits at different temperatures of the drying air, as well as obtain the thermodynamic properties involved in the drying process of the product. Drying was carried out under controlled conductions of temperature (60, 70, 80, 90 and 100 °C) using three samples of 130 g of fruit, which were weighed periodically until constant mass. The experimental data were adjusted to different mathematical models often used in the representation of fruit drying. Effective diffusion coefficients, calculated from the mathematical model of liquid diffusion, were used to obtain activation energy, enthalpy, entropy and Gibbs free energy. The Midilli model showed the best fit to the experimental data of drying of 'Cabacinha' pepper fruits. The increase in drying temperature promoted an increase in water removal rate, effective diffusion coefficient and Gibbs free energy, besides a reduction in fruit drying time and in the values of entropy and enthalpy. The activation energy for the drying of pepper fruits was 36.09 kJ mol^{-1}.

Palavras-chave:
Capsicum chinense L.
razão de umidade
entalpia
energia de ativação

Cinética e propriedades termodinâmicas relacionadas à secagem dos frutos de pimenta Cabacinha

RESUMO

Objetivou-se, neste trabalho, determinar e modelar a cinética de secagem dos frutos de pimenta Cabacinha para diferentes temperaturas do ar de secagem, bem como obter as propriedades termodinâmicas envolvidas no processo de secagem do produto. A secagem foi realizada em condições controladas de temperatura (60, 70, 80, 90 e 100 °C) utilizando-se três amostras de 130 g de frutos, as quais foram pesadas periodicamente até atingirem massa constante. Os dados experimentais foram ajustados a diferentes modelos matemáticos frequentemente utilizados na representação da secagem de frutos. O coeficiente de difusão efetivo, calculado a partir do modelo matemático da difusão líquida, foi utilizado para obtenção da energia de ativação, entalpia, entropia e energia livre de Gibbs. O modelo de Midilli foi o que apresentou os melhores ajustes aos dados experimentais da secagem dos frutos de pimenta Cabacinha. A elevação da temperatura de secagem promoveu: o aumento nos valores da taxa de remoção de água dos frutos, do coeficiente de difusão efetivo e da energia livre de Gibbs além de redução no tempo de secagem dos frutos, nos valores da entalpia e a entropia. A energia de ativação para a secagem dos frutos de pimenta foi de 36,09 kJ mol^{-1}.

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Introduction

The varieties of the pepper species *Capsicum chinense* L. stand out for their great diversity of fruits with different forms, flavors, aromas, pungencies and chemical compositions. These characteristics justify their wide use in human consumption, medicine and cosmetic industries (Dagnoko et al., 2013).

The pepper market is characterized for being very diversified, since the fruits are commercialized fresh and processed, in sauces, picklings and seasonings (Henz & Moretti, 2008). Kaleemullah & Kailappan (2004) point out that, for being stored with high water contents, pepper and bell pepper fruits may suffer physico-chemical and biological alterations, thus reducing the commercial value of the product (Henz & Moretti, 2008).

The drying of agricultural and food products has been one of the strategies adopted and successfully used in the conservation of the quality of various products. Drying pepper fruits, for instance, allows reducing the high water contents to levels adequate for storing, which consequently decreases biological activity in the fruits and the problems regarding deterioration and contamination (Srinivasakannan & Balasubramanian, 2009).

The knowledge on the thermodynamic properties, which include enthalpy, entropy and Gibbs free energy, related to the process of drying of agricultural products, provides information necessary to project drying devices, study the properties of the absorbed water (Corrêa et al., 2010) and calculate the necessary energy demand in drying processes (Martins et al., 2015).

Enthalpy provides a measurement of the variation of the binding energy between water molecules and the constituents of the product during the process of sorption (Jideani & Mpotokwana, 2009). Entropy is related to the degree of disorder (Goneli et al., 2010), i.e., it is associated with the spatial arrangement of the water-product relationship (Jideani & Mpotokwana, 2009). Gibbs free energy, on the other hand, is a parameter used in the evaluation of spontaneity of water desorption (Corrêa et al., 2010).

Based on the above, this study aimed to determine and model the drying kinetics of 'Cabacinha' pepper fruits and obtain the thermodynamic properties involved in the drying process of the product.

Material and Methods

The study was conducted at the Laboratory of Seed Analysis (LAS) of the Federal Institute of Education, Science and Technology of Goiás - Campus Ceres (IF Goiano - Câmpus Ceres), in the municipality of Ceres-GO, Brazil.

'Cabacinha' pepper fruits (strain IFET 1541) were used in the experiment, which were manually harvested at maturation (Henz & Moretti, 2008), defined by their orange color. The fruits were washed in running water and selected, discarding the ones with injuries; then, they were placed in plastic bags and maintained in a refrigerator (temperature of 4.20 ± 0.72 and 66.2 ± 5.10% of relative air humidity - RH), until the drying process (Reis et al., 2011).

The water content in the fruits was determined by the standard oven method, at 103 ± 1 °C for 24 h, in four replicates (ASABE, 2010).

The fruits were dried in a forced-air oven adjusted to temperatures of 60, 70, 80, 90 and 100 °C, with respective RH values of 10.5, 6.6, 4.5, 2.8 and 2.2%. For the drying temperature, three metallic trays (dimensions: 26.7 cm long, 9.7 cm wide and 7.2 cm high) were filled with 130 g of product, forming a single layer with thickness of approximately 9.5 cm. During the drying process, the water content of the fruits was gravimetrically monitored, by weighing the samples periodically on an analytical scale (resolution of 0.01 g) until they reached the water content at hygroscopic equilibrium, i.e., when the variation in the mass of the containers did not exceed 0.01 g in three consecutive weighings (Corrêa et al., 2010).

Water removal rate (WRR) of 'Cabacinha' pepper fruits was calculated using Eq. 1.

$$\mathrm{WRR}=\frac{\mathrm{Mw}_0-\mathrm{Mw}_i}{\mathrm{Md}\cdot\left(t_i-t_0\right)} \tag{1}$$

where:

WRR - water removal rate, kg kg^{-1} h^{-1};
Mw_0 - previous total mass of water, kg;
Mw_i - current total mass of water, kg;
Md - mass of dry matter, kg;
t_0 - previous total time of drying, h; and
t_i - current total time of drying, h.

For the determination of moisture ratios (RX) during the drying process under different conditions of temperature and relative air humidity, the following expression was used (Santos et al., 2012; Morais et al., 2013):

$$\mathrm{RX}=\frac{X-X_e}{X_i-X_e} \tag{2}$$

where:

X - water content of the product, decimal (d.b.);
X_i - initial water content of the product, decimal (d.b.); and
X_e - water content at hygroscopic equilibrium of the product, decimal (d.b.).

Moisture ratio data were used for the adjustment of 10 mathematical models, employed to represent the drying of different types of fruits (Vega et al., 2007; Pontes et al., 2009; Corrêa et al., 2010; Reis et al., 2011; Moraes et al., 2013), according to the expressions in Table 1.

For the adjustment of the mathematical models, a non-linear regression analysis was performed through the Gauss-Newton method. The degree of adjustment of each model was verified considering the magnitude of the adjusted coefficient of determination (R^2), standard deviation of estimate (SE), residual sum of squares (RSS) and the tendency of residual distribution (Goneli et al., 2011; Reis et al., 2011; Moraes et al., 2013). SE and RSS were calculated using the following expressions, respectively:

Table 1. Mathematical models used to predict the drying phenomenon

Model designation	Model	n°
Approximation of Diffusion	$RX = a \exp(-k\,t) + (1 - a) \exp(-k\,b\,t)$	(3)
Two-Term	$RX = a \exp(-k\,t) + b \exp(-c\,t)$	(4)
Logarithmic	$RX = a \exp(-k\,t) + b$	(5)
Midilli	$RX = a \exp(-k\,t^{b}) + c\,t$	(6)
Modified Midilli	$RX = \exp(-k\,t^{n}) + a\,t$	(7)
Newton	$RX = \exp(-k\,t)$	(8)
Page	$RX = \exp(-k\,t^{n})$	(9)
Modified Page	$RX = \exp(-(k\,t)^{n})$	(10)
Verna	$RX = a \exp(-k\,t) + (1 - a) \exp(-b\,t)$	(11)
Wang and Singh	$RX = 1 + (a\,t) + (b\,t^{2})$	(12)

t - Drying time; h; k - Drying coefficient, s^{-1}; a, b, c, n - Parameters of the models, dimensionless

$$SE = \sqrt{\frac{\sum_{i=1}^{n}\left(Y - \hat{Y}\right)^{2}}{DF}} \qquad (13)$$

$$RSS = \frac{1}{n} \cdot \sum_{i=1}^{n}\left(Y - \hat{Y}\right)^{2} \qquad (14)$$

where:

Y - experimental value;
Y - value estimated by the model;
n - number of experimental observations; and
DF - degrees of freedom (number of observations minus the number of parameters of the model).

The mathematical model of liquid diffusion using the analytical solution for the cylindrical geometric form (Brooker et al., 1992), with eight-term approximation (Eq. 15), was adjusted to the experimental data of drying of pepper fruits, disregarding its volumetric contraction (Reis et al., 2011).

$$RX = \frac{X - X_e}{X_i - X_e} = \sum_{n=1}^{\infty} \frac{4}{\lambda_n^{2}} \cdot \exp\left[-\frac{\lambda_n^{2} \cdot D_{ef} \cdot t}{r}\right] \qquad (15)$$

where:

D_{ef} - effective diffusion coefficient, $m^2\ s^{-1}$;
λ - roots of the Bessel's equation of zero order;
n - number of terms;
r - equivalent sphere radius, 0.0048 m; and
t - time, s.

For the determination of the initial equivalent radius, defined as the radius of a sphere with volume equivalent to that of 'Cabacinha' pepper fruits (Mohsenin, 1986), four replicates of 25 fruits were used, which had the orthogonal axes (length, width and thickness) measured using a digital caliper with resolution of 0.01 mm (Corrêa et al., 2010).

In order to evaluate the influence of the drying temperature on the effective diffusion coefficient, the Arrhenius equation was adjusted according to the following expression:

$$D_{ef} = D_0 \cdot \exp\left(-\frac{E_a}{R \cdot T_a}\right) \qquad (16)$$

where:

D_0 - pre-exponential factor, $m^2\ s^{-1}$;
E_a - activation energy, $kJ\ mol^{-1}$;
R - universal gas constant, 8.314 $kJ\ mol^{-1}\ K^{-1}$; and
T_a - absolute temperature, K.

The thermodynamic properties (enthalpy, entropy and Gibbs free energy) related to the drying process of pepper fruits were calculated using the method described by the universal gas constant, through the following equations, respectively:

$$\Delta H = E_a - R \cdot T_a \qquad (17)$$

$$\Delta S = R \cdot \left[\ln\left(D_0\right) - \ln\left(\frac{k_B}{h_P}\right) - \ln\left(T_a\right)\right] \qquad (18)$$

$$\Delta G = \Delta H - T_a \cdot \Delta S \qquad (19)$$

where:

ΔH - specific enthalpy, $J\ mol^{-1}$;
ΔS - specific entropy, $J\ mol^{-1}\ K^{-1}$;
ΔG - Gibbs free energy, $J\ mol^{-1}$;
k_B - constant of Boltzmann, $1.38 \times 10^{-23}\ J\ K^{-1}$;
h_P - constant of Planck, $6.626 \times 10^{-34}\ J\ s^{-1}$; and
T_a - absolute temperature, K.

RESULTS AND DISCUSSION

The initial water content of 'Cabacinha' pepper fruits was approximately 6.038 (decimal, d.b.); on the other hand, the water contents at hygroscopic equilibrium, obtained at the end of the drying process at the temperatures of 60, 70, 80, 90 and 100 °C, were 0.069, 0.066, 0.051, 0.017 and 0.021 (decimal, d.b.), respectively. The reduction in equilibrium water content with the increase in drying air temperature was also observed for fruits of green bell pepper (Silva et al., 2008), 'Pimenta-de-cheiro' (Pontes et al., 2009) and 'Cumari-do-Pará' pepper (Reis et al., 2011).

The statistical parameters used for the comparison between the models adjusted to the experimental data of drying of pepper fruits, under the different drying conditions, are shown in Table 2.

The analyzed models showed coefficients of determination (R^2) above 0.9792, standard deviation of estimate (SE) below 0.079 (decimal) and residual sum of squares (RSS) lower than 0.604 (decimal, x 10^{-2}).

According to Draper & Smith (1998), the lower the value of SE, the better will be the quality of the fit in relation to the experimental data. In the present study, this same selection criterion was also adopted for RSS.

Among the adjusted models, Midilli (Eq. 6) showed the highest coefficients of determination ($R^2 > 0.9990$) and the lowest standard deviations of estimate ($SE < 0.018$) and residual sum of squares ($RSS < 0.029 \times 10^{-2}$), thus proving to be an adequate fit to the experimental data of drying of pepper fruits under the different drying conditions evaluated.

Table 2. Coefficients of determination (R^2), standard deviation of estimate (SE, decimal), residual sum of squares (RSS, decimal x 10^{-2}) and behavior with respect to the residual distribution (RD) for the models adjusted to the experimental data of drying the 'Cabacinha' pepper fruits

Models	R^2	SE	RSS	RD	R^2	SE	RSS	RD	R^2	SE	RSS	RD
		60 °C				70 °C				80 °C		
Approximation of Diffusion	0.9977	0.024	0.054	BD	0.9944	0.041	0.154	BD	0.9908	0.054	0.270	BD
Two-Term	0.9846	0.062	0.361	BD	0.9855	0.066	0.397	BD	0.9974	0.030	0.078	RD
Logarithmic	0.9979	0.023	0.050	BD	0.9957	0.036	0.119	BD	0.9931	0.047	0.203	BD
Midilli	0.9991	0.015	0.020	RD	0.9990	0.018	0.029	RD	0.9991	0.017	0.026	RD
Modified Midilli	0.9990	0.016	0.025	RD	0.9988	0.019	0.033	RD	0.9989	0.019	0.032	RD
Newton	0.9797	0.070	0.477	BD	0.9792	0.076	0.569	BD	0.9793	0.079	0.604	BD
Page	0.9969	0.028	0.074	RD	0.9980	0.024	0.055	RD	0.9987	0.020	0.038	RD
Modified Page	0.9969	0.028	0.074	RD	0.9980	0.024	0.055	RD	0.9987	0.020	0.038	RD
Verna	0.9842	0.062	0.372	BD	0.9836	0.070	0.449	BD	0.9840	0.072	0.468	BD
Wang and Singh	0.9988	0.017	0.028	BD	0.9973	0.028	0.075	BD	0.9962	0.034	0.111	BD
		90 °C				100 °C						
Approximation of diffusion	0.9889	0.060	0.329	BD	0.9888	0.061	0.329	BD	-	-	-	-
Two-term	0.9875	0.065	0.371	BD	0.9883	0.064	0.345	BD	-	-	-	-
Logarithmic	0.9916	0.052	0.248	BD	0.9916	0.053	0.247	BD	-	-	-	-
Midilli	0.9992	0.017	0.025	RD	0.9992	0.017	0.025	RD	-	-	-	-
Modified Midilli	0.9990	0.018	0.031	RD	0.9990	0.018	0.029	RD	-	-	-	-
Newton	0.9803	0.078	0.582	BD	0.9812	0.076	0.552	BD	-	-	-	-
Page	0.9989	0.019	0.033	RD	0.9990	0.018	0.030	RD	-	-	-	-
Modified Page	0.9989	0.019	0.033	RD	0.9990	0.018	0.030	RD	-	-	-	-
Verna	0.9846	0.071	0.454	BD	0.9883	0.076	0.510	BD	-	-	-	-
Wang and Singh	0.9944	0.042	0.167	BD	0.9927	0.048	0.217	BD	-	-	-	-

BD - Biased distribution; RD - Random distribution

In the analysis of drying kinetics of 'Cumari-do-Pará' pepper (*Capsicum chinense* Jacquin), at the temperatures of 45, 55 and 65 °C and 'Cambuci' pepper (*Capsicum baccatum*) at the temperatures of 40, 50 and 60 ºC, Reis et al. (2011) and Derlan et al. (2013) also observed that the Midilli model showed the best fit to the experimental data.

As to the residual distribution (Table 2), only the models of Midilli (Eq. 6), modified Midilli (Eq. 7), Page (Eq. 9) and modified Page (Eq. 10) showed random residual distribution for the five temperatures studied.

The residual distribution was considered as random when the values of residues were close to the horizontal line, around zero, and did not form defined figures, indicating that there is no tendency in the results. When the residues showed biased distribution, the model was considered as inadequate to represent the studied phenomenon. However, for having random residual distribution and the best statistical parameters (R^2, SE and RSS) for all the studied temperatures (Table 2), the Midilli model (Eq. 6) was selected to represent the drying kinetics of 'Cabacinha' pepper fruits for the temperatures of 60, 70, 80, 90 and 100 °C (Figure 1A).

According to Figure 1A, the times necessary for pepper fruits to reach the water contents at hygroscopic equilibrium were 29, 18, 14.5, 13 and 10.5 h, for the temperatures of 60, 70, 80, 90 and 100 °C, respectively. Similar behaviors were observed by Reis et al. (2011) in studies with 'Cumari-do-Pará' pepper and by Moraes et al. (2013), studying 'Dedo-de-moça' pepper.

Still in Figure 1B, the maximum values (0.402, 0.728, 0.926, 1.312 and 2.010 kg kg^{-1} h^{-1}) of water removal rate (WRR) occurred after 5.5, 2.5, 1.5, 1.5 and 0.8 h of drying, respectively for the temperatures of 60, 70, 80, 90 and 100 °C. The increase

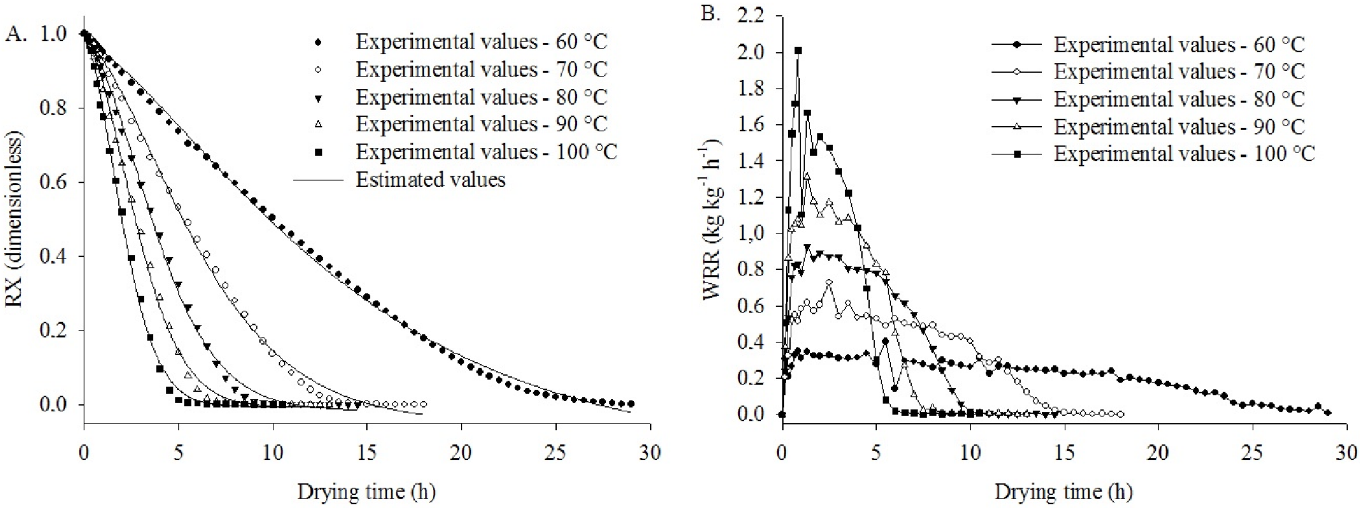


Figure 1. Experimental values and values estimated by the Midilli model for the moisture ratio (RX; A) and water removal rate (WRR, B) as a function of the drying time of 'Cabacinha' pepper fruits

in drying temperature reduced the time necessary to reach the highest WRR values, evidencing the increment in the water potential gradient existing between the fruits and the drying air. The influence of air temperature on water removal rate was also reported by Corrêa et al. (2001).

The parameters of the Midilli model for each drying temperature and the respective equations are shown in Table 3. The equations used to estimate each coefficient as a function of the drying air temperature showed high coefficients of determination ($R^2 > 0.9342$) and regression coefficients significant at 0.01 probability level by t-test. In addition, only the "a" coefficient did not show variation tendency as a function of temperature; thus, its mean value was used (a = 0.979).

The values of the effective diffusion coefficient and the Arrhenius representation as a function of the drying temperature of pepper fruits are shown in Figure 2.

In Figure 2, the increase in drying temperature promoted increment in the values of the effective diffusion coefficient and reduction in the Arrhenius representation. According to Goneli et al. (2014), when temperature increases, water viscosity decreases and, since viscosity is a measurement of fluid resistance to flowing, variation in this property lead to alterations in water diffusion in the capillaries of pepper fruits.

For the drying of 'Cabacinha' pepper fruits in the temperature range of 60 to 100 °C, the effective diffusion coefficient ranged from 4.07×10^{-9} to 21.42×10^{-9} $m^2\ s^{-1}$, respectively. These values are considered as high compared with those obtained by Srinivasakannan & Balasubramanian (2009) for green pepper (1.95×10^{-11} to 7.00×10^{-11} $m^2\ s^{-1}$), Reis et al. (2011) for 'Cumari-do-Pará' pepper (2.29×10^{-11} to 2.57×10^{-11} $m^2\ s^{-1}$) and Derlan et al. (2013) for 'Cumari-do-Pará' (2.39×10^{-10} to 5.08×10^{-10} $m^2\ s^{-1}$) in the temperature ranges of 50 to 70, 45 to 65 and 40 to 60 °C, respectively.

The difference between the values of the effective diffusion coefficient for the different types of pepper is due to physical characteristics (Martins et al., 2015), water content and forms of processing of each fruit (Derlan et al., 2013). Rizvi (1995) points out that the diffusion coefficient is also dependent on drying air temperature, variety and composition of the materials, besides other factors.

As observed in Figure 2B, both the effective diffusion coefficient and the Arrhenius representation can be expressed by linear equations, thus agreeing with the results obtained by Kaleemullah & Kailappan (2006), Reis et al. (2011), Derlan et al. (2013) and Martins et al. (2015).

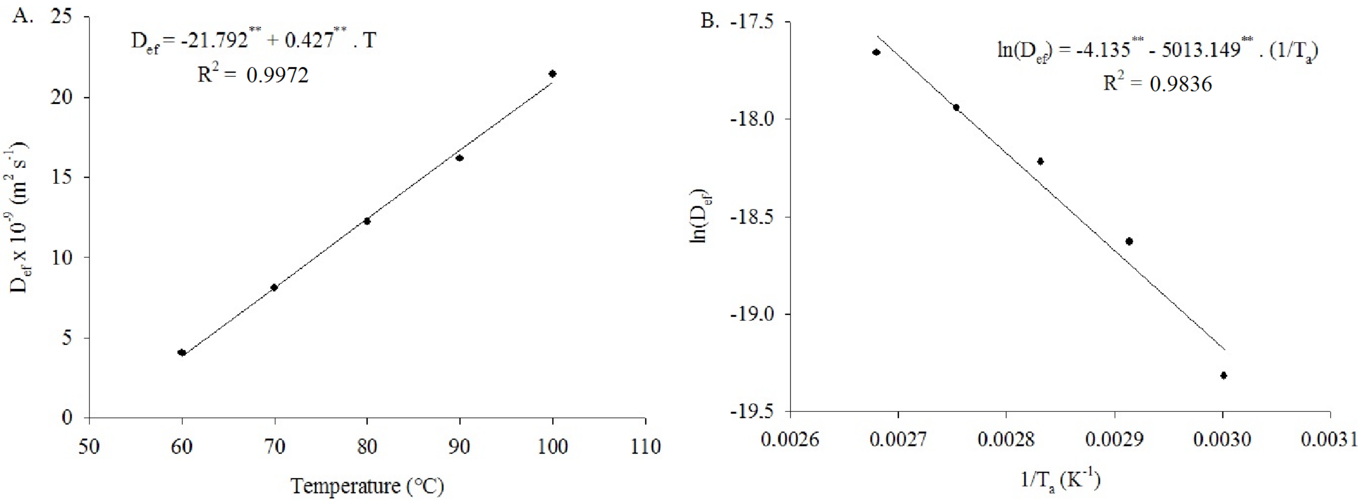
According to Goneli et al. (2014), the slope of the Arrhenius representation provides the E_a/R relationship, while its intersection with the Y-axis indicates the value of D_o; thus, the activation energy (Eq. 21) of the water diffusion of 'Cabacinha' pepper fruits was equal to 36.09 kJ mol^{-1}. This value is consistent with those found by Kaleemullah & Kailappan (2006) for red pepper (37.76 kJ mol^{-1}) and Vega et al. (2007) for red bell pepper (39.70 kJ mol^{-1}).

$$D_{ef} = \left(2.468 \cdot 10^{-3}\right) \cdot \exp\left(-\frac{36{,}093.144}{R \cdot T_a}\right) \qquad (20)$$

Table 3. Midilli model coefficients and adjusted equations as a function of drying air temperature for 'Cabacinha' pepper fruits

Coefficients	Temperature (°C)					Equations	R^2
	60	70	80	90	100		
a	0.9778	0.9814	0.9779	0.9765	0.9803	$a = 0.979^{*}$	ns
k	0.0267	0.0503	0.0797	0.1235	0.2097	$k = 0.001^{**} . \exp(0.048^{**} . T)$	0.9829
n	1.3754	1.5455	1.6604	1.6950	1.6713	$n = -1.573^{**} + 0.073^{**} . T + (-4.054^{**} . 10^{-4}) . T^2$	0.9342
b	-0.0029	-0.0021	-0.0010	-0.0006	-0.0005	$b = -0.024^{**} + (5.049^{**} . 10^{-4}) . T + (-2.685^{**} . 10^{-6}) . T^2$	0.9787

*Mean value; ** Significant at 0.01 by t-test; ^{ns}Not significant



** Significant at 0.01 by t-test

Figure 2. Mean experimental values and estimated values of the effective diffusion coefficient (D_{ef}; A) and Arrhenius representation for the effective diffusion coefficient ($\ln(D_{ef})$; B) as a function of the drying air temperature of 'Cabacinha' pepper fruits

The activation energy is related to the amount of energy necessary to trigger the process of water diffusion (Martins et al., 2015); thus, the lower the activation energy, the higher will be the water diffusivity of the product, i.e., the lower will be the energy necessary to transform liquid free water into vapor (Corrêa et al., 2010).

The mean values of enthalpy, entropy and Gibbs free energy as a function of drying temperature of pepper fruits are shown in Table 4.

Enthalpy decreased from 333.23 x 10^2 to 329.91 x 10^2 J mol^{-1} with the increase in temperature from 60 to 100 °C (Table 4). Corrêa et al. (2010) obtained similar values for the drying of coffee (*Coffea arabica* L.) at the temperatures of 35, 45 and 55 °C, with enthalpy variations of 358.28 x 10^2, 357.45 x 10^2 and 356.62 x 10^2 J mol^{-1}, respectively. These authors concluded that this characteristic is an indication that lower amount of energy is required for the drying process to occur at higher temperatures.

Entropy, which is related to the degree of excitation and spatial arrangement of water molecules in relation to the product (Jideane & Mptokawana, 2009; Goneli et al., 2010), ranged from -295.75 to -296.69 J mol^{-1} K^{-1} for the temperature range of 60 to 100 °C (Table 4). Thus, the lowest values of entropy for the highest temperatures indicate that, under this condition, there is lower excitation of water molecules, i.e., there is a higher degree of order between water molecules and the pepper fruits. In addition, the negative values of entropy can be attributed to the existence of chemical alteration or modifications in the structure of the product during the drying process (Corrêa et al., 2010).

Gibbs free energy increased from 131.85 x 10^3 to 143.70 x 10^3 J mol^{-1}, with the increase in temperature from 60 to 100 °C (Table 4); positive values indicate that drying is a non-spontaneous process, i.e., it requires an additional energy from the environment surrounding the product for the reaction to occur (Corrêa et al., 2010).

Table 4. Enthalpy (ΔH), entropy (ΔS) and Gibbs free energy (ΔG) as a function of drying air temperature of ‘Cabacinha’ pepper fruits

Thermodynamic properties	Temperature (°C)				
	60	70	80	90	100
ΔH x 10^2 (J mol^{-1})	333.233	332.402	331.571	330.739	329.908
ΔS (J mol^{-1} K^{-1})	-295.751	-295.997	-296.235	-296.468	-296.693
ΔG x 10^3 (J mol^{-1})	131.853	134.811	137.773	140.736	143.702

CONCLUSIONS

1. The Midilli model showed the best fit to the experimental data of drying of ‘Cabacinha’ pepper fruits and was selected to represent this phenomenon.

2. The increase in drying temperature promoted a reduction in the time necessary for the fruits to reach the water content at hygroscopic equilibrium.

3. With the increase in drying temperature, there was an increase in effective diffusion coefficient and Gibbs free energy and a reduction in the values of enthalpy and entropy.

4. The activation energy for the drying of pepper fruits at the temperatures of 60, 70, 80, 90 and 100 °C was 36.09 kJ mol^{-1}.

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