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COFFEE CHERRIES DRYING PROCESS AND THE INFLUENCE OF ENVIRONMENT RELATIVE HUMIDITY IN THE MATHEMATICAL MODELING, MOISTURE CONTENT, AND ENTHALPY OF VAPORIZATION

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ABSTRACT: The drying operation is one of the most important stages of the coffee production. Thus, we aimed to evaluate the influence of the ambient relative humidity (40, 50 and 60%) in the natural process of coffee (*Coffea Arabica* L.) drying at different air temperatures (23 °C, 40 °C and 60 °C) using mathematical modeling, equilibrium moisture content, and enthalpy of vaporization. Coffee cherries natural processed and dried with a drier of fixed layer was used. The study was conducted at the Department of Engineering and Technology Center of Post-Harvest Café, of the Federal University of Lavras. The results showed that the equilibrium water content of the coffee cherry is directly proportional to the water activity, and decreased increasing temperature during the same water activity. The Oswin model showed the best fit to describe the phenomenon of hygroscopicity of the coffee cherry. The latent heat of desorption increased decreasing the water content and decreased increasing temperatures of the same water content. In addition, the Midilli model showed the best fit to the drying data. Furthermore, the Gibbs free energy increased increasing temperature, it's their magnitude being was positive in the temperature range used in this study. In conclusion, the different ambient relative humidities did not significantly influenced the processes of drying coffee cherries.

KEYWORDS: quality, dimensioning, project, dryer.

SECAGEM DE CAFÉ CEREJA E A INFLUÊNCIA DA UMIDADE RELATIVA DO AR AMBIENTE NA MODELAGEM MATEMÁTICA, EQUILÍBRIO HIGROSCÓPICO E NA ENTALPIA DE VAPORIZAÇÃO

RESUMO: A secagem é uma das etapas mais importantes no processamento de café. Assim, o objetivo foi avaliar a influência da umidade relativa do ar ambiente (40, 50 e 60%) na secagem do café natural (*Coffea arábica* L.) em diferentes temperaturas (23 °C, 40 °C e 60 °C) com modelagem matemática, o equilíbrio higroscópico e a entalpia de vaporização. O trabalho foi realizado no Departamento de Engenharia e Centro de Tecnologia de Pós-Colheita Café, Universidade Federal de Lavras. No experimento foi utilizado café cereja, processamento de forma natural e seco em camada fixa. Nos resultados obtidos observou-se que o teor de água de equilíbrio do café cereja é diretamente proporcional à atividade da água e diminui com o aumento da temperatura, para uma mesma atividade de água. O modelo de Oswin apresentou-se melhor para o ajuste e descrição do fenômeno de higroscopicidade o café cereja. O calor latente de dessorção aumentou com a diminuição do teor de água e diminui com o aumento da temperatura, para o mesmo conteúdo de água. O modelo de Midilli foi o melhor, para o ajuste dos dados experimentais de secagem. Além disso, a energia livre de Gibbs aumentou com o aumento da temperatura, sendo as suas grandezas positivas na gama de temperatura utilizada neste estudo. Em conclusão, as diferentes umidades relativas do ar ambiente não influenciaram significativamente nos processos de secagem do café.

PALAVRAS-CHAVE: qualidade, dimensionamento, projeto, secador.

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1 INTRODUCTION

The phenomenon of reducing the grain moisture content involves, simultaneously, the transfer of heat and mass, whichcan substantially change the quality and physical properties of the product, depending on the method used and drying conditions (LACERDA FILHO et al., 2006). The development and improvement of equipment used to dry grains is of fundamental importance to do the simulation and to obtain theoretical information about the behavior of each product. The simulation is based on successive thin layers drying mathematical model that mean to dry as one layer of sample particles or slices and represents satisfactorily the loss of water during the drying rate period (BORÉM et al., 2008). Thin layer drying models have the purpose to determine the product drying rates from data recorded of the mass loss from the sample occurred during water removal (MONTE et al., 2008).

Thus, thin layer drying model vary with species, variety, environmental conditions, methods staging post harvest, among other factors. Accordingly, various mathematical models have been used to describe the drying of agricultural products, although in most cases, the semi-empirical and empirical relationships have been shown to predict the best options for drying grains and seeds, although its validity is restricted to the conditions under which the experimental data were obtained (CORRÊA et al., 2006). These models generally are based on external variables, such as temperature and air relative humidity. However, there are no indication that the energy and water transport phenomena inside the grains occurs only in the period of decreasing rate.

The semi-empirical equations are based on Newton's law of cooling, assuming that the drying condition is isothermal and that the water transfer is restricted to the surface of the product. Numerous studies have been conducted in order to identify the characteristics of various agricultural products during drying processes as: beans (RESENDE et al., 2007), grape (RAMOS et al., 2005), seeds ockra (DOYMAZ, 2005), pie (LAHSASNI et al., 2004), carrots (DOYMAZ, 2004), tomato (DOYMAZ, 2007a), pumpkin (DOYMAZ, 2007b), parboiled wheat (MOHAPATRA & RAO, 2005), among others.

Like any hygroscopic material, coffee beans have the property to absorb water from the environment, constantly tending to maintain a balanced relationship between the material moisture content and with the ambient air. The equilibrium moisture content, also called hygroscopic equilibrium moisture is the moisture content at which the vapor pressure of water in the product is equal to the surrounding air (SOKHANSANJ et al., 1996). According to Hall (1980) the establishment of equilibrium moisture curves is important to set limits to the product dehydration, estimate the changes of moisture under certain conditions of temperature and relative humidity of the environment, and to define the water content amenable to early active agents that will cause deterioration of the product. For coffee, it is important to emphasize that the drying conditions and proper storage are essential to maintain the quality of its products due to its high water content and to the presence of microorganisms during harvesting.

Whereas, the knowledge of the thermodynamic properties in agricultural products drying processes is important to design drying equipment, study the properties of adsorbed water, calculate the energy required in this process, and also to evaluate the microstructure of foods and the study of physical phenomena that occur on the surface of the food (CORRÊA et al. 2010). By studying the thermodynamic properties of a product, we try to troubleshoot the issues of stability and optimize industrial processes conditions. Enthalpy changes provide the energy variation measurement when there is an interaction between the water molecules and the product constituents during the processes of sorption or desorption. The enthalpy of vaporization, also known as the (latent) heat of vaporization or heat of evaporation, is the amount of energy required for a molecule of an element that is in equilibrium with its own vapor to pass through to the gaseous state, that will indirectly influence the energy consumption, drying time, and product quality (CORRÊA et al. 2010).

Given that drying coffee on bare ground or with mechanical dryers is taken at temperatures 20-60 °C, with better quality results at temperatures near 40 °C, and that the effects of relative humidity are not controlled during drying, the aim of this work was evaluate the influence of the relative humidity of ambient air (40, 50 and 60%) on the natural drying coffee (*Coffea Arabica* L.) process at different air temperatures (23 °C, 40 °C and 60 °C) using mathematical modeling, equilibrium moisture content, and enthalpy of vaporization analyses.

2 MATERIAL AND METHODS

The experiment was conducted at the Department of Engineering and Technology Center of Post-Harvest Coffee at Federal University of Lavras. Coffee variety Topazio cherries were selectively manually harvested with water content of 48% (w.b.). For each repetition, there were collected 800 liters. All raw materials were washed, separated, green coffees were manually selected, to standardize the raw materials. Then about 150 liters of coffee cherries were taken directly to the yard.

Some of the natural coffee was divided into distinct segments in the yard, where they stayed for two days, then the fruits were taken for mechanical drying with water content of 27% (w.b.), the same environmental conditions of relative humidity. During the time that coffee has remained at the yard, every half hour, the coffee was stirred and the temperature and relative humidity of the ambient air were moritored using a term hygrograph. Mechanical drying was conducted on two prototypes of fixed layer. To obtain the air flow diafragram a graduated opening in the fan inlet was used. The average air velocity was measured by an anemometer blade at the end and in the center of the inlet plenum and above the perforated plate plenum without the mass of coffee.. The air flow was set to 20 m³ min^{-1} m^{-2}, according to RIBEIRO et al. (2005), obtained with the equation 1.

$$\Phi = Q/A \qquad (1)$$

wherein,
Φ: air flow (m³ min^{-1} m^{-2})
Q: air mass flow rates (m³ min^{-1})
A: area of the input plenum, 0.0318 m²

During the drying process the coffee mass temperature and the ambient air temperature and relative humidity were monitored periodically. The temperature of the coffee mass was measured every 30 minutes with using aid of type J thermocouples placed in the center of the coffee pile in each division of the drying chamber. To minimize a possible temperature difference between the four divisions due to the position of the resistances in the plenum we performed a rotation of the samples every hour. The coffee cherries water content measurements were collected at the end of the morning and late in the afternoon, during the first five days, and then, daily in the late afternoon, reaching the level of water storage of 11% (w.b.). In mechanical drying, water content measurements were each hour. The determination of the water content was performed by standard oven at 105 ± 3 °C for 24 hours (BRASIL, 2009). The moisture meter G-800 was used in order to monitor the grains water content. Every hour, a sample was collected for processing and determination of water content. When the coffee mass reached a water content of 11% (w.b.), the drying was stopped.

The drying curves were fitted to the experimental data using thirteen different semi-empirical and empirical equations discriminated below:

Equation	Model	
$RU = \exp(-k \cdot t)$	Newton	(2)
$RU = \exp(-k \cdot t^n)$	Page	(3)
$RU = \exp(-(\ k \cdot t\ )^n)$	Page Modified	(4)
$RU = \exp\ (-\ a-\ (a^2 + 4 \cdot b \cdot t)^{1/2})\ /\ 2 \cdot b$	Thompson	(5)
$RU = a \cdot \exp(-k \cdot t)$	Henderson and Pabis	(6)
$RU = a\exp(-kt) + c$	Logarithmic	(7)
$RU = a \cdot \exp(-k_o \cdot t) + b \cdot \exp(-k_1 \cdot t)$	Two Terms	(8)
$RU = a \cdot \exp(-k \cdot t) + (1-a)\exp(-k \cdot a \cdot t)$	Two Exponential Terms	(9)
$RU = 1 + a\,t + b\,t^2$	Wang and Singh	(10)
$RU = a \cdot \exp(-k \cdot t) + b \cdot \exp(-k_o \cdot t) + c \cdot \exp(-k_1 \cdot t)$	Henderson and Pabis Modified	(11)
$RU = a \cdot \exp(-k \cdot t^n) + b \cdot t$	Midilli	(12)
$RU = a \cdot \exp(-k \cdot t) + (1-a) \cdot \exp(-k \cdot b \cdot t)$	Diffusion approximation	(13)

wherein RU = moisture ratio (dimensionless) t = drying time (h), k, k$_o$, k$_1$ = drying constant (h^{-1}), a, b, c = model coefficients, n = number of terms of the equation, D = diffusion coefficient (m^2 s^{-1}), L = product thickness (m).

For determining the ratios of moisture during drying air under different conditions we used the following expression:

$$RU = \frac{U^* - U_e^*}{U_i^* - U_e^*} \qquad (14)$$

wherein U* = water content of product (d.b.), Ui* = initial water content of the product (d.b.), Ue* = equilibrium water content of the product (d.b.).

It is usual to consider the value of the diffusion coefficient constant or linearly dependent on the temperature of the air drying. This relationship has been expressed by the Arrhenius model (MOHAPATRA et al., 2005).

$$D = A\exp\left(-\frac{E}{RT}\right) \qquad (15)$$

wherein A = constant (m^2 s^{-1}), E = activation energy (kJ kmol^{-1}), R = universal gas constant (8,314 kJ kmol^{-1} K^{-1}), T$_{abs}$ = absolute temperature (K).

The coefficients of the Arrhenius expression were linearized by applying the logarithm of the form:

$$\mathrm{LnD} = LnA - \frac{E}{RT}\frac{1}{Ta} \qquad (16)$$

Data was analyzed using analysis of variance and regression using F test, adopting the 5% level of significance. To evaluate the influence of temperature on diffusion coefficient, the Arrhenius equation was used, described as follows:

$$K = K_o \cdot \exp\left(\frac{E_a}{R \cdot T_a}\right) \qquad (17)$$

wherein K = parameter analyzed, K_o = pre-exponential factor, E_a = activation energy (kJ mol^{-1}), R = universal gas constant, (8,314 kJ $kmol^{-1}$ K^{-1}), T_a = absolute temperature (K).

The dynamic-gravimetric method was used to obtain the coffee fruits water content in hygroscopic equilibrium. Desorption thin layer of the product was performed for different controlled conditions of temperature (23, 40, and 60 °C) and relative humidity of the air drying, 40, 50 and 60% until the product has reached the equilibrium moisture content with air condition specified. Temperature and relative humidity were monitored by means of a psychrometer installed next to the trays containing the samples. During the drying period, the trays were weighed periodically and the hygroscopic equilibrium was reached when the mass change of the containers remain unchanged for three consecutive weighings. Equilibrium water content experimental data was adjusted using mathematical models that are frequently used to represent the hygroscopic agricultural products, which expressions shown below:

Model designation	Model	
Sigma Copace	$U_e^* = \exp\{a - (b \cdot T) + [c \cdot \exp(a_w)]\}$	(18)
Sabbah	$U_e^* = a \cdot \left(a_w{}^{b} / T^{c}\right)$	(19)
Oswin	$U_e^* = (a + b\,T) / \left[(1 - a_w)/a_w\right]^{1/c}$	(20)
Henderson	$U_e^* = [\ln(1 - a_w)/(-a \cdot T + 273{,}16)]^{1/b}$	(21)
Henderson Modified	$U_e^* = \{\ln(1 - a_w)/[-a \cdot (T + b)]\}^{1/c}$	(22)
Halsey Modified	$U_e^* = [\exp(a - b \cdot T)/-\ln(a_w)]^{1/c}$	(23)
GAB	$U_e^* = (a \cdot b \cdot c \cdot a_w)/[(1 - c \cdot a_w) \cdot (1 - c \cdot a_w + b \cdot c \cdot a_w)]$	(24)
Copace	$U_e^* = \exp[a - (b \cdot T) + (c \cdot a_w)]$	(25)
Chung Pfost	$U_e^* = a - b \cdot \ln[-(T + c) \cdot \ln(a_w)]$	(26)
BET	$U_e^* = \{1/[(1 - a_w) \cdot (1/a \cdot b + ((a-1)/a \cdot b))]\}$	(27)

wherein Ue* = equilibrium water content (d.b.), a_w = water activity (decimal), T = temperature (°C), a, b, c = coefficients that depend on the product.

The values of the isosteric heat of desorption liquid was obtained by the equation.

$$\ln(a_w) = -\left(\frac{q_{st}}{R}\right) . \frac{1}{T} + C \qquad (28)$$

wherein C = coefficient model.

The values of water activity, temperature, and water content equilibrium was obtained from the coffee fruits desorption isotherms, using the model that best fit the experimental data. For the calculation of the integral isosteric heat of desorption we used the following equation:

$$Q_{st} = q_{st} + L = a \cdot \exp(-b \cdot U_e^*) + L \qquad (29)$$

wherein Q_{st} = integral isosteric heat of sorption (kJ kg^{-1}), L = latent heat of vaporization of free water (kJ kg^{-1}), Ue* = equilibrium water content (d.b.), a, b = coefficient model.

The free water latent heat of vaporization was obtained using the average temperature by the following equation:

$$L = 2502{,}2 - 2{,}39.T_m \qquad (30)$$

wherein L = latent heat of vaporization of free water (kJ kg^{-1}), T_m = average temperature (°C).

The experimental design was a completely randomized design (CRD) with three tests for each relative humidities and drying temperatures. Nonlinear regressions were performed to adjust the mathematical models analysis based on Quasi-Newton method, using the computer program STATISTICA 7.0®. To check the fit degree of each model, the significance of the regression coefficient was determined by t-test, adopting the 5% level of probability, the magnitude of the coefficient of determination (R^2), the mean relative error values (P), the average estimated error (SE) and the behavior of distribution of residuals was verified. The relative average error and the average error estimated for each model were calculated according to the following expressions, respectively:

$$P = \frac{100}{n} \sum \frac{\left|Y - \hat{Y}\right|}{Y} \qquad (31)$$

$$SE = \sqrt{\frac{\sum \left(Y - \hat{Y}\right)^2}{GLR}} \qquad (32)$$

Wherein Y = experimentally observed value, $\hat{Y}$ = value calculated by the model, n = number of experimental observations, GLR = degrees of freedom of the model (the number of observations minus the number of model parameters).

3 RESULTS AND DISCUSSION

Table 1 shows the models parameters estimates observed for the hygroscopic coffee fruits obtained by the desorption process, in different conditions of temperature and water activity. Analyzing the results in Table 1, it was found that the mathematical models used to describe the hygroscopicity of coffee showed significant regression parameters, at 5% probability level by the t test. Except for the models Henderson, Halsey Modified, GAB, Chung Pfost e BET, the coefficient of determination obtained were above 0.97 for all drying treatments. While the mean relative errors for these same models were below 10%, indicating that suitable for the description of the phenomenon studied (CORRÊA et al., 2006) MOHAMED et al., 2008; MOHAPATRA & RAO, 2005; PENA et al., 2010).

It was also found that, among the tested models Sigma Copace, Sabbah, Henderson Modified, Copace, Corrêa, and specially the Oswin's (Table 1) were the ones with random distribution of residues, that means that these models have a setting most appropriate to the experimental data, regardless of the relative humidity conditions during the drying period. Conditions of relative humidity did not affect the drying treatments. According to Corrêa et al. (2006), the ability to model adequately represent a specific physical process is inversely proportional to the estimated average error value. Thus, among the models evaluated, Oswin was the one that best fit the experimental data, showing a high coefficient of determination and lower average relative errors. In the Figure 1 the coffee fruits equilibrium water content observed and predicted curves are show no, that were obtained by desorption and isotherm calculated using the Oswin model.

***Table 1** - Parameter values estimated, mean relative error (P), standard deviation of the estimate (SE), coefficient of determination (R^2) and residual distribution for the model mathematical of Oswin to drying fruits of coffee (Coffea arabica L.) under the relative humidity average of 40, 50 and 60%*

Estimation of parameters*	R² (%)	P (%)	SE (decimal)	R
RH = 50%				
a = 0.010934 b = -0.000052 c = 0.063877	99.79	0.17981	0.0009	A
RH = 50%				
a = 0.008169 b = -0.000031 c = 0.081433	99.82	0.12809	0.0006	A
RH = 60%				
a = 0.004836 b = -0.000025 c = 0.078500	99.96	0.09320	0.0004	A

*All estimated coefficients were significant at 5% probability by t test. A – Aleatory, R – Distribution of residue.

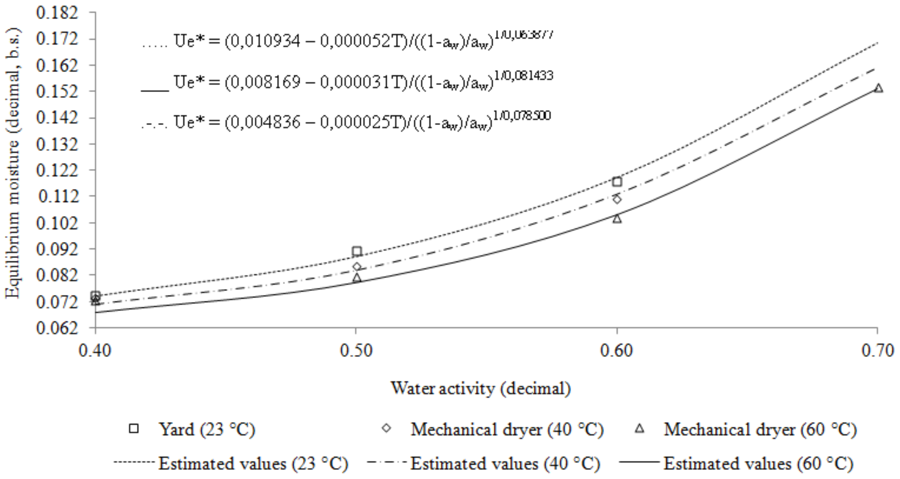


***Figure 1** - Observed and predicted values by Oswin model of water content equilibrium moisture content of the natural coffee obtained by desorption for different conditions of temperature and water activity. * Significant at 1% probability by the t test.*

It was found that, for a constant water activity value of equilibrium water content decreased with increasing temperature of the air drying The sorption isotherms of coffee cherries (Figure 1) showed sigmoid shape tendencies of food and biological materials can be observed an increase in moisture from water activities in the range of 0.5. This behavior is common in foods with high sugar contents, which have the property of absorbing large or small amounts of water, according to the relative humidity (GONELI et al., 2011; MONTE et al., 2008; RESENDE et al., 2011; ULLMAN et al., 2010). The results of the isotherms obtained can serve as handle suitable for stored products, in order to maintain the levels of water at the recommended levels for safe storage between 12-14% (w.b.). The graphics of sorption isotherms can be used also to define the region’s most suitable form to storage coffee, considering the weather conditions, especially temperature and relative humidity. The Oswin model was used to calculate the water activity required for determining the values of the isosteric heat of desorption liquid, once the model has proved to be satisfactory in representing the equilibrium moisture content of the coffee. Figure 2 shows a variation in the isosteric heat of desorption and on the latent heat of water vaporization, as the temperature increased from 23 to 60 °C reducing the equilibrium moisture content in the product by increasing the energy required to remove water. Similar results were obtained by other researchers and other agricultural products, as grape (RAMOS et al., 2005), seeds ockra (DOYMAZ, 2005), parboiled wheat (MOHAPATRA & RAO, 2005), beans (RESENDE et al., 2011), acai (PENA et al., 2010), wheat (GONELI et al., 2007). On the other hand, the ambient relative humidity had little influence on the variation of the isosteric heat of desorption.

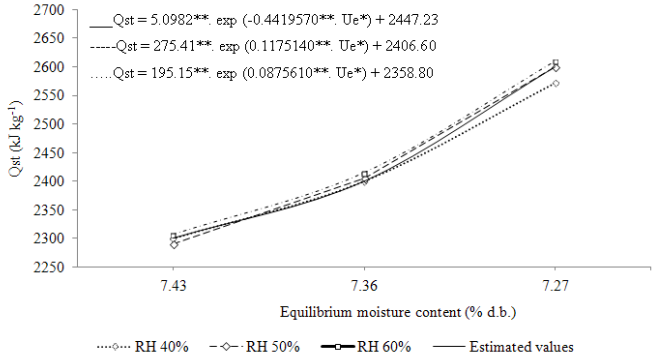


Figure 2 *- Experimental values and estimated integral isosteric heat of sorption as a function of moisture content equilibrium.**Significant at 1% probability by the t test. *Significant at 5% probability by the t test.*

The drying time was directly influenced by the temperature of the drying air, so that, the higher the temperature the lower the time to complete the drying independent of the ambient air conditions. On the other hand, it was also observed that the higher the relative humidity of the ambient air during the drying period the water content equilibrium and time required to complete the process were higher. This fact was observed by several researchers (GONELI et al., 2007; LAHSASNI et al., 2004; MOHAMED et al., 2008; MOHAPATRA & RAO, 2005; PENA et al., 2010).

The coefficients of the models adjusted for coffee cherry natural, analyzed during drying at different drying air temperatures and relative humidity conditions of the air are in table 2. Among the models that gave good statistics results (Table 3), the model Midilli was selected to represent the phenomenon of drying coffee due to its simplicity compared to other models and also was selected to present a number of significant coefficients. From Midilli model, it was observed that the drying coefficients "k”, "a", and "b" increased with increasing temperature and decreasing relative humidity, while the constant "n" decreased with increasing temperature and decreasing relative humidity. The coefficients "k”, "a", and " b" represent the effects of external drying conditions, according to Babalis et al. (2006), the constant "k”, "a", and "b" can be used as an approach to characterize the effect of temperature related to the effective diffusivity in the drying process period and the descending liquid diffusion controlling the process. While the constant "n" reflects the internal strength of the product drying.

For Corrêa et al. (2006), Verma model satisfactorily represented the *Coffea Arabica* fruits phenomenon of drying. However, Babalis et al. (2006) and Mohamed et al. (2008) noted that the model of Two Terms got best fit the experimental data of fig and dried seaweeds (*Gelidium sesquipedale*), respectively. Martinazzo et al. (2007) found that the best model for drying sheets of lemon grass is the Midilli, which also considered flat plate and noticed that the drying coefficient "k" increased with increasing temperature, and the constant "n" decreased confirming the data obtained in this study. A similar result was found by Radünz et al. (2010), that studied sage leaves drying conditions under room temperature between 40 and 90 °C and concluded that the models Handerson, Pabis, and Midilli were those that the best represented the drying kinetics for sage leaves.

The coefficient of determination is a good parameter to check the fit of nonlinear models and typically has higher values for the models that best fit the experimental data. Thus, it was observed that for most treatments, the coefficients of determination R^2 were above 97%, indicating, as according to Corrêa et al. (2006), a satisfactory representation of the phenomenon under study. The Midilli model showed the lowest values of the mean relative error for the conditions of 40% relative humidity in air drying at 23 °C, 40 °C, and 60 °C (Table 3).

Where as the exponential models, Two Terms, Two Exponential Terms, and broadcast approach, under 50% RH, the Midilli model resulted in the lowest values of mean error relative to all drying temperatures, confirming its unsuitability in the representation of the phenomenon under study for this product. Between the drying temperatures, the errors were smaller on average to 60 °C. With the exception of models Modified, Page, Eight Terms, and broadcast all other studied mathematical models for this product had errors estimated average below 10%.

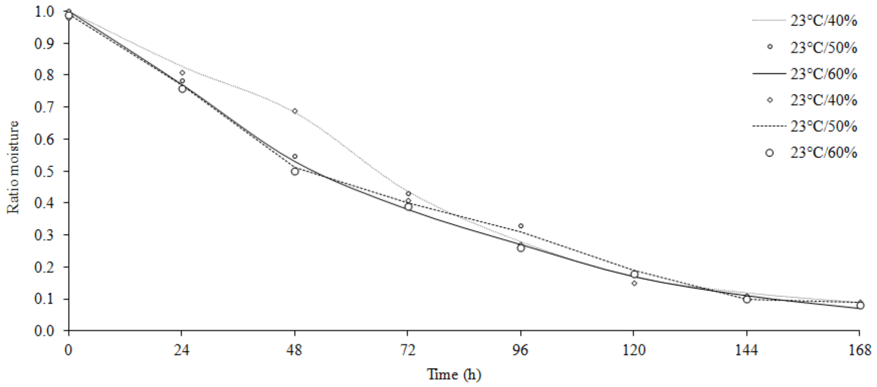
Note that the models used, satisfactorily fit the phenomenon of drying the natural coffee. Even with the initial water content of the coffee being equal, the time required for the product to reach the equilibrium water content was variable, depending on the drying air temperature and relative humidity. At the end of the drying period, the water removal rate slowed and the discrepancies between the values of the water content of the product reduced. One can infer that this fact occurs possibly due to the tendency of the coffee reaches equilibrium moisture content similar to the average conditions of the drying air.

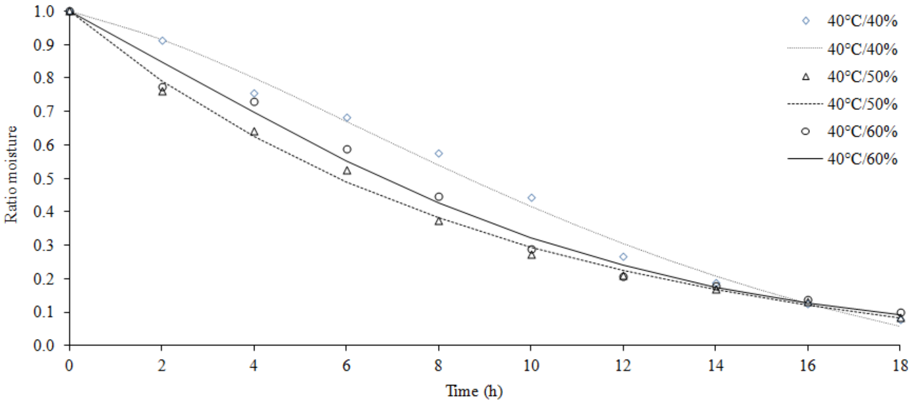
Table 3 - *Coefficients of determination (R^2), mean relative errors (P) and mean estimated errors (SE) for the Midilli model analyzed during drying of the cherry coffee under various temperature conditions and relative humidity of 40, 50 and 60%*

RH	Temperature air drying	Parameters evaluated			
		R² (%)	P (%)	SE (decimal)	R
40%	23 °C	99.72	0.89	0.0008	A
	40 °C	99.23	0.46	0.0018	A
	60 °C	99.93	0.16	0.0002	A
50%	23 °C	99.59	0.29	0.0010	A
	40 °C	98.66	0.55	0.0025	A
	60 °C	99.64	0.07	0.0008	A
60%	23 °C	99.58	0.77	0.0012	A
	40 °C	99.56	0.04	0.0010	A
	60 °C	99.82	0.84	0.0004	A

A – Aleatory , R – Distribution of residue.

Figure 3 the drying curves for the natural coffee as estimated by the Midilli at temperatures of 23, 40 and 60 °C, and relative humidity of 40, 50 and 60% are shown in figure 3.





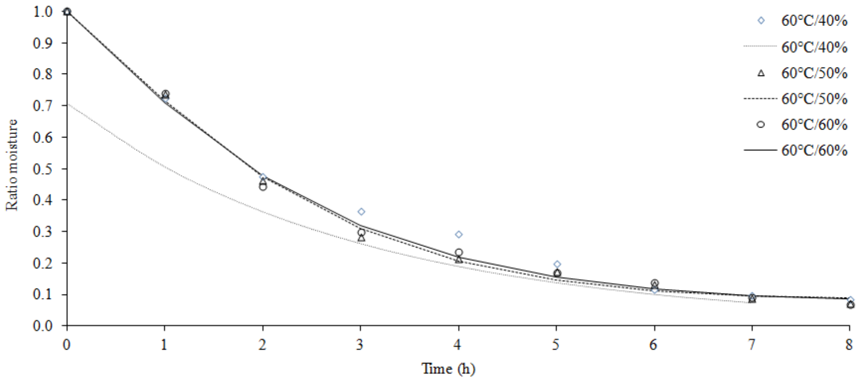


Figure 3 - *Drying curves adjusted with Midilli model for natural coffee at different temperatures and relative humidity.*

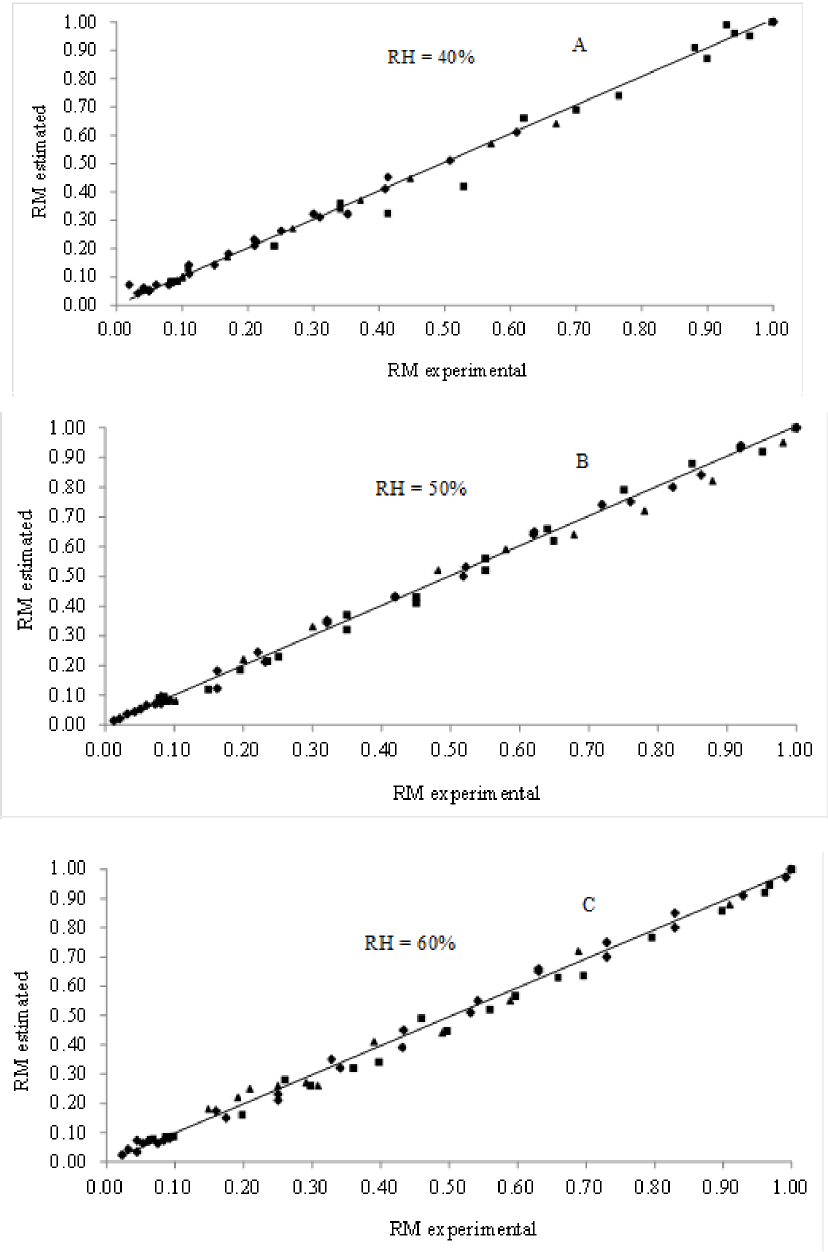


Figure 4 - *Experimental and estimated values of the ratio moisture for 40 (A), 50 (B) and 60 (C) % of relative humidity of the air estimated by parameters of the Midilli equation.*

The activation energy found for the temperatures of 23, 40 and 60 °C was 7.8, 8.34 and 8.43 KJ mol^{-1}, respectively. The activation energy is a barrier that must be overcome so that the diffusion process can be triggered in the product (KASHANINEJAD et al., 2007). According to Kashaninejad et al. (2007), the activation energy decreases with increasing initial water content of the product during the drying process.

4 CONCLUSION

The coffee cherry equilibrium water content is directly proportional to the water activity and decreased increasing the temperature in the same water activity. The Oswin model showed the best fit to describe the phenomenon of hygroscopicity in coffee cherries. The latent heat of desorption increased decreasing the water content and decreased increasing the temperatures for the same water content. The Midilli model was best-fit model to the experimental results. The Gibbs free energy increased when the temperature increased increasing temperature, their magnitudes stayed positive with all the temperature range used in this study. The differences on the air relative humidity ranges did not significantly influence the drying coffee cherries processes.

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