Drying kinetics of ‘gueroba’ (Syagrus oleracea) fruit pulp

Cinética de secagem da polpa dos frutos de gueroba (Syagrus oleracea)

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ABSTRACT: The ‘Gueroba’ fruit can be used to produce flours with potential for the development of new products from the ‘Cerrado’ socio-biodiversity. The objective was to estimate the drying kinetics and determine the effective diffusion coefficient and activation energy for the pulp of ‘gueroba’ fruits subjected to different drying temperatures. ‘Gueroba’ fruits were manually pulped, removing the mesocarp with the epicarp, and this material was identified as the pulp. The material was subjected to oven drying at temperatures of 40, 50, 60 and 70 °C. Nonlinear regression models were fitted to the experimental data. The most adequate model was selected through the coefficient of determination, mean relative and estimated errors, Chi-square test, AIC and BIC. As the drying temperature increases, the processing time to achieve the same moisture content decreases, due to the increase in water diffusivity inside the product. The Midilli model showed the best fit to the experimental data obtained. The effective diffusion coefficients of the pulp of ‘gueroba’ fruits showed magnitudes between 3.11 x 10⁻⁹ to 5.84 x 10⁻⁹ m² s⁻¹ for temperatures from 40 to 70 °C. The activation energy of the process was 18.34 kJ mol⁻¹.

Key words: mathematical modeling, AIC, BIC, Midilli

RESUMO: O fruto de gueroba pode ser utilizado na produção de farinhas com potencial para o desenvolvimento de novos produtos oriundos da sociobiodiversidade do Cerrado. Objetivou-se estimar a cinética de secagem, bem como determinar o coeficiente de difusão efetivo e a energia de ativação para a polpa dos frutos de gueroba submetida a diferentes temperaturas de secagem. Os frutos de gueroba foram despolpados manualmente, retirando o mesocarpo com o epicarpo, sendo esse material identificado como a polpa. O material foi submetido à secagem em estufa nas temperaturas de 40, 50, 60 e 70 °C. Aos dados experimentais foram ajustados modelos de regressão não lineares. O modelo mais adequado foi selecionado através do coeficiente de determinação, erro relativo e estimado, teste de Qui-quadrado, AIC e BIC. Com o aumento da temperatura de secagem, menor é o tempo do processamento para atingir o mesmo teor de água, devido ao aumento da difusividade da água no interior do produto. O modelo de Midilli apresentou o melhor ajuste aos dados experimentais obtidos. Os coeficientes de difusão efetivos da polpa dos frutos de gueroba apresentaram magnitudes entre 3,11 x 10⁻⁹ a 5,84 x 10⁻⁹ m² s⁻¹ para as temperaturas de 40 a 70 °C. A energia de ativação do processo foi de 18,34 kJ mol⁻¹.

Palavras-chave: modelagem matemática, AIC, BIC, Midilli
**Introduction**

‘Gueroba’ (*Syagrus oleracea*) is a typical palm tree of the ‘Cerrado’ and is known in Goiás as ‘gueroba’ or ‘guariroba’, whereas in other regions of Brazil it is popularly known as ‘guarirrova’, ‘palmito amargoso’ and ‘catole’. Its fruits have yellowish-green color with thick, fleshy, fibrous and sweetened mesocarp (Lorenzi et al., 2004).

The pulp of the fruits can be used for the extraction of oils and the by-product in the production of flours for food supplementation. The pulp of this fruit is rich in nutrients and sources of fats, besides having significant amounts of carbohydrates. The pulp oil is rich in unsaturated fatty acids (ISPN, 2013).

The fruits are harvested with high moisture content, which makes their storage difficult, so it is necessary to reduce the moisture content of the product. Therefore, the processing of pulp into flour by the drying method can be an efficient alternative to increase the shelf life of the fruits.

The drying process is extremely important in food technology, as it allows the handling of high-quality products, since it can preserve their physical and chemical properties and reduce the moisture content to adequate values for storage. Thus, the product can be used in periods with no availability of the fruit (Resende et al., 2018).

Drying can be estimated through curves fitted to experimental data by nonlinear regression models frequently used to estimate this process (Sousa et al., 2017; Souza et al., 2019). From this drying kinetics, many authors study the behavior of water inside the product, determining the water diffusivity and activation energy (Corrêa et al., 2007; Goneli et al., 2014; Guimarães et al., 2018).

The objective of this study was to estimate the drying kinetics and determine the effective diffusion coefficient and activation energy for the pulp of ‘gueroba’ fruits subjected to drying temperatures.

**Material and Methods**

‘Gueroba’ fruits were collected in the rural area of the municipality of Piracanjuba, Goiás, Brazil, at 17° 17' 47" S latitude, 49° 0' 38" W longitude and altitude of 752 m.

The fruits were harvested and sent to the Laboratory of Postharvest of Plant Products at the Instituto Federal Goiano, Campus of Rio Verde, Goiás, Brazil. Then, the fruits were selected and manually pulped using a stainless-steel knife, removing the mesocarp adhered to the epicarp, and the sum of these two structures was called the pulp of the ‘gueroba’ fruit. The initial moisture content was determined in an oven at 105 °C until constant mass was reached (Oliveira et al., 2018).

As the ‘gueroba’ pulp is a fibrous material, a spatula was used to homogenize it, turning the material without degrading its structure. Subsequently, the material was subjected to drying in a forced air ventilation oven (Marconi, MA-035), in three replicates, in perforated trays (25 cm in diameter) with a 2.5-cm-thick layer and 500 g of pulp, at temperatures of 40, 50, 60 and 70 °C, which promoted relative humidity of the drying air inside the oven of 27.15, 16.23, 10.05 and 7.07%, respectively.

Drying was performed up to the final moisture content of 0.125 ± 0.024 d.b., as it is an ideal moisture content for the processing of flour of this product, besides being an adequate value for storage. The reduction of moisture content was monitored by the gravimetric method (mass loss) (Resende et al., 2018), using a scale with resolution of 0.01 g.

The ambient temperature and the temperature inside the dryer were monitored using a thermometer, and the relative humidity of the air inside the oven was obtained through the basic principles of psychometry, with the computer program GRAPSI. The moisture contents of the product were determined in an oven at 105 °C up to constant mass (± 24 h).

To obtain the hygroscopic equilibrium, three replicates containing 20 g of pulp were maintained under the previously described drying conditions and periodically weighed until reaching constant mass. The moisture content ratios of the product were determined by Eq. 1:

\[
RX = \frac{X - X_e}{X_i - X_e}
\]

where:

- \(RX\) - moisture content ratio, dimensionless;
- \(X\) - moisture content of the product, d.b.;
- \(X_i\) - initial moisture content of the product, d.b.; and,
- \(X_e\) - equilibrium moisture content of the product, d.b.

‘Gueroba’ pulp drying was represented by the nonlinear regression models described in Table 1, which are commonly used for products of plant origin.

| Table 1. Models used to predict the drying of ‘gueroba’ fruit pulp |
|-----------------------|-----------------------|-----------------------|
| **Model**              | **Model designation**  | **Eq.**               |
| \(RX = 1 + at + bt^2\) | Wang and Singh         | (2)                   |
| \(RX = a \exp(-kt) + (1-a)\exp(-kt)\) | Verma                  | (3)                   |
| \(RX = \exp\left(\{-a - (a^2 + 4bt)^{1/2}\}/2b\right)\) | Verma                  | (4)                   |
| \(RX = \exp(-kt\)\)   | Page                   | (5)                   |
| \(RX = \exp(-kt)\)   | Newton                 | (6)                   |
| \(RX = a \exp(-kt) + bt\) | Midilli                | (7)                   |
| \(RX = a \exp(-kt) + c\) | Logarithmic            | (8)                   |
| \(RX = a \exp(-kt)\) | Henderson and Pabis    | (9)                   |
| \(RX = a \exp(-kt) + (1-a)\exp(-kat)\) | Two-Term Exponential   | (10)                  |
| \(RX = a \exp(-kt) + b \exp(-kt)\) | Two Terms              | (11)                  |
| \(RX = a \exp(-kt) + (1-a)\exp(-kt)\) | Approximation of Diffusion | (12)                |

\(t\) - Drying time; \((h, k, a, b, c, n)\) - Drying constants; \(h, k\) - Coefficients of the models

The models were fitted to the experimental drying data, by nonlinear regression analysis performed with the Gauss-Newton method using R software. The values reported in the literature for the modeling of other plant products were adopted as a criterion for the initial values of the coefficients of the models.

The degree of fit at each drying temperature was determined initially based on the magnitude of the coefficient of determination \((R^2)\), the values of the mean estimated error \((SE)\) and the mean relative error \((P)\), as well as the Chi-square test \((\chi^2)\) at significance level of 5% and confidence interval at 95% (\(p < 5\)).

\[
SE = \sqrt{\frac{\sum(Y - \hat{Y})^2}{DF}}
\]

\(Y\) - Observed value; \(\hat{Y}\) - Estimated value; \(DF\) - Degrees of freedom
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\[ P = \frac{100}{N} \sum \left( \frac{Y - \hat{Y}}{Y} \right) \]  

(14)

\[ \chi^2 = \frac{\sum(Y - \hat{Y})^2}{DF} \]  

(15)

where:

\( Y \) - value observed experimentally;
\( \hat{Y} \) - value estimated by the model;
\( n \) - number of experimental observations; and,
\( DF \) - residual degrees of freedom (number of experimental observations minus the number of model parameters).

To choose a single regression model that best describes the drying process of the pulp of 'gueroba' fruits, additional criteria were used. For the models that obtained better fits according to the previously listed criteria, the Akaike Information Criterion (AIC) and the Schwarz's Bayesian Information Criterion (BIC) were calculated using Eqs. 16 and 17:

\[ \text{AIC} = -2 \log \text{like} + 2p \]  

(16)

\[ \text{BIC} = -2 \log \text{like} + 2p \ln (n) \]  

(17)

where:

\( p \) - number of parameters of the model;
\( n \) - total number of observations; and,
\( \log \text{like} \) - value of the logarithm of the likelihood function considering the estimates of the parameters.

The relationship between the effective diffusion coefficient and the elevation of the drying air temperature was described using the Arrhenius equation (Eq. 20).

\[ D = D_0 \exp \left( \frac{E_a}{RT_{abs}} \right) \]  

(20)

where:

\( D_0 \) - pre-exponential factor, m² s⁻¹;
\( E_a \) - Activation energy, kJ mol⁻¹;
\( R \) - Universal constant of gases, 8.134 kJ kmol⁻¹ K⁻¹; and,
\( T_{abs} \) - absolute temperature, K.

With application of the logarithm, the coefficients of the Arrhenius equation were linearized (Eq. 21).

\[ \ln D = \ln D_0 + \left( \frac{E_a}{RT_{abs}} \right) \]  

(21)

**Results and Discussion**

Table 2 shows that, for all models used, at the four drying temperatures, the values of the mean estimated error (SE) were close to zero, indicating a good fit to the experimental data. According to Draper & Smith (1998), the closer the SE value is to zero, the better its ability to adequately represent a physical process, in this case the drying.

It is also verified that, for all models and drying conditions, except the Wang and Singh model for drying temperatures of 40 and 60 ºC, the coefficients of determination (R²) were greater than 99% (Table 2). Higher R² values indicate a better representation of the studied phenomenon by the model, but it cannot be taken as the main criterion for nonlinear estimates (Oliveira et al., 2018).

In relation to the mean relative error (P), Table 2 shows that the Midilli and Logarithmic models had lower values for all drying temperatures; in addition to these, the Henderson and Pabis, Two-Term Exponential and Two terms models had P values below 10%. For Mohapatra & Rao (2005), this is a condition that determines good fit of the model to the drying conditions. It can be noted that, for the Chi-square test (Table 2), all models had low values, and the lower this value, the better the fit of the model to the conditions, as reported by Günhan et al. (2005). Midilli and Logarithmic models were the ones that obtained the best fit to the drying conditions.
As shown in Table 3, these two models had similar values for AIC and BIC. According to results presented by Ferreira Junior et al. (2018), lower values for these criteria indicate better fit of the model to the data of the phenomenon.

The Midilli model showed lower values of both AIC and BIC under the drying conditions, so this was the model chosen to represent the drying of the pulp of 'gueroba' fruits. Gomes et al. (2018), working with the drying of jambu leaves, also used the AIC and BIC criteria to select the most adequate model.

It can be observed in Table 4 that the magnitude of the drying constant k for the Midilli model increased linearly with the increase in drying air temperature.

The drying constant k represents the external drying conditions, can be used as an approximation to characterize the effect of temperature, and is related to the effective diffusivity in the drying process in the falling rate period (Babalis & Belessiotis, 2004). The coefficients a, n and b (Table 4) showed no trend with the increase in drying temperature, showing different behavior from that of the constant k.

Figure 1 shows the drying curves of the pulp of 'gueroba' fruits estimated by the Midilli model. The initial moisture content of the fruit pulp was 2.40 decimal on dry basis (d.b.). Through the correspondence between the experimental values and those estimated by the model, it can be observed that there was satisfactory fit of the model to the data obtained along the drying of 'gueroba' fruit pulp.

To reach the final moisture content of 0.125 ± 0.024, times of 6.25, 5.25, 5 and 3 h were necessary for the temperatures

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\[ k = 0.0098T - 0.1441 \quad \left( R^2 = 0.8968 \right) \]  \hspace{1cm} (22)
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of 40, 50, 60 and 70 °C, respectively (Figure 1). It was noted that the time spent is inversely proportional to the drying temperature, that is, the higher the temperature, the shorter the time over which the product will be subjected to drying. The behavior of drying time as a function of temperature has been observed by several researchers, studying the drying of cactus pear pulp (Madureira et al., 2011), sunflower grains (Smaniotto et al., 2017), and mesocarp of ‘baru’ fruits (Oliveira et al., 2018), because the higher the temperature, the higher the diffusivity of water under these conditions.

The effective diffusion coefficient of ‘gueroba’ fruit pulp (Figure 2A) increases linearly with the increment in the drying air temperature. This behavior corroborates the results obtained by other researchers, for the study of the drying kinetics of passion fruit peel (Bezerra et al., 2015) and drying of the sliced pulp of biofortified sweet potato (Souza et al., 2019).

The effective diffusion coefficients (Figure 2A) of ‘gueroba’ fruit pulp showed magnitudes from $3.11 \times 10^{-9}$ to $5.84 \times 10^{-9}$ m$^2$ s$^{-1}$ for temperatures from 40 to 70 °C. The magnitudes of the effective diffusion coefficients of the drying of ‘acuri’ slices ranged from $3.28 (60 \, ^{\circ} \text{C})$ to $5.53 \times 10^{-10}$ m$^2$ s$^{-1}$ (90 °C) (Santos et al., 2019). The values of the effective diffusivity of the drying of ‘gueroba’ fruits are below those found by Sousa et al. (2017) in the drying of pequi pulp, in which the effective diffusivity under the different drying conditions varied from $0.93 \times 10^{-8}$ to $3.93 \times 10^{-8}$ m$^2$ s$^{-1}$, for the temperature range from 50 to 80 °C, respectively.

Water diffusivity inside the product is dependent on drying air temperature, that is, the higher the drying air temperature, the higher the rate of vibration of the water molecules inside the product, resulting in a decrease in the resistance of the fluid to the flow (Goneli et al., 2014), promoted by the reduction in water viscosity.

The Arrhenius expression (Figure 2B) was used to represent the dependence of the effective diffusion coefficient of ‘gueroba’ fruit pulp on the drying temperature. The activation energy found for the drying kinetics was 18.34 kJ mol$^{-1}$. The activation energy for plant products is between 12.7 and 110 kJ mol$^{-1}$, so the value found in this study is within this range (Zogzas et al., 1996).

For slices of ‘acuri’ (*Attalea phalerata*), the activation energy of drying was 17.66 kJ mol$^{-1}$ (Santos et al., 2019). For drying of okara (soybean residue) in the range from 40 to 70 °C, the activation energy was 28.15 kJ mol$^{-1}$ (Guimarães et al., 2018). The difference between the activation energy values for the same temperature range can be explained by the difference in the composition of the products.

The activation energy represents the degree of difficulty encountered by water molecules to overcome the energy barrier in the migration inside the product (Corrêa et al., 2007). The higher the value of the activation energy, the lower the water diffusivity of the product, due to the low mobility of water inside the product. Thus, the pulp of ‘gueroba’ fruits is relatively easy to be dried, when compared to the mesocarp (pulp) of baru fruits, which has activation energy of 27.005 kJ mol$^{-1}$ within the same temperature range used in this study (Oliveira et al., 2018).
CONCLUSIONS

1. Increase in drying temperature reduces the drying time from 6.25 to 3 h at drying temperatures of 40 °C and 70 °C, respectively.

2. The Midilli model showed the best fit to the experimental data of ‘gueroba’ fruit pulp drying at different temperatures.

3. The effective diffusion coefficients of the pulp of ‘gueroba’ fruits showed magnitudes from $3.11 \times 10^{-9}$ to $5.84 \times 10^{-9}$ m$^2$ s$^{-1}$ at temperatures from 40 to 70 °C.

4. The Arrhenius equation confirmed the dependence of the effective diffusion coefficient on the drying temperature, in which the activation energy found for the drying phenomenon was 18.3434 kJ mol$^{-1}$.

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LITERATURE CITED

Afonso Júnior, P. C.; Corrêa, P. C. Comparação de modelos matemáticos para descrição da cinética de secagem em camada fina de sementes de feijão. Revista Brasileira de Engenharia Agrícola e Ambiental, v.3, p.349-353, 1999. https://doi.org/10.1590/1807-1929/agriambi.v3n3p349-353

Babalas, S. J.; Belessiotis, V. G. Influence of the drying conditions on the drying constants and moisture diffusivity during the thin-layer drying of figs. Journal of Food Engineering, v.65, p.449-458, 2004. https://doi.org/10.1016/j.jfoodeng.2004.02.005

Bezerra, C. V. B.; Silva, L. H. M. da; Corrêa, D. F.; Rodrigues, A. M. C. A modeling study for moisture diffusivities and moisture transfer coefficients in drying of passion fruit peel. International Journal of Heat and Mass Transfer, v.85, p.750-755, 2015. https://doi.org/10.1016/j.ijheatmasstransfer.2015.02.027

Brooker, D. B.; Bakker-Arkema, F. W.; Hall, C. W. Drying and storage of grains and oilseeds. Westport: Te Avi Publishing Company, 1992. 450p.

Corrêa, P. C.; Resende, O.; Martinazzo, A. P.; Goneli, A. L. D.; Botelho, F. M. Modelagem matemática para a descrição do processo de secagem do feijão (Phaseolus vulgaris L.) em camadas delgadas. Engenharia Agrícola, v.27, p.501-510, 2007. https://doi.org/10.1016/j.jfoodeng.2004.02.005

Draper, N. R.; Smith, H. Applied regression analysis. 3.ed. New York: John Wiley & Sons, 1998. 712p. https://doi.org/10.1002/9781118625590

Ferreira Junior, W. N.; Resende, O.; Oliveira, D. E. C. de; Costa, L. M. Isotherms and isosteric heat desorption of Hymenaea stigonocarpa Mart. seeds. Journal of Agricultural Science, v.10, p.504-512, 2018. https://doi.org/10.5359/jas.v10n1p504

Galdino, P. O.; Figueiredo, R. M. F. de; Queiroz, A. J. de M.; Galdino, P. O. Drying kinetics of atemoya pulp. Revista Brasileira de Engenharia Agrícola e Ambiental, v.20, p.672-676, 2016. https://doi.org/10.1590/1807-1929/agriambi.v20n7p672-677

Gomes, F. P.; Resende, O.; Sousa, E. P. de; Oliveira, D. E. C. de; Araújo Neto, F. R. de. Drying kinetics of crushed mass of ‘jambu’: Effective diffusivity and activation energy. Revista Brasileira de Engenharia Agrícola e Ambiental, v.22, p.499-505, 2018. https://doi.org/10.1590/1807-1929/agriambi.v22n7p499-505

Goneli, A. L. D.; Vieira, M. do C.; Vilhasanti, H. da C. B.; Gonçalves, A. A. Modelagem matemática e difusividade efetiva de folhas de areoaria durante a secagem. Pesquisa Agropecuária Tropical, v.44, p.56-64, 2014. https://doi.org/10.1590/S1983-40632014000100005

Guimarães, R. M.; Oliveira, D. E. C. de; Resende, O.; Silva, J. de S.; Resende, T. A. M. de; Egea, M. B. Thermodynamic properties and drying kinetics of okara. Revista Brasileira de Engenharia Agrícola e Ambiental, v.22, p.418-423, 2018. https://doi.org/10.1590/1807-1929/agriambi.v22n6p418-423

Günhan, T.; Demir, V.; Hancioglu, E.; Hepbasli, A. Mathematical modelling of drying of bay leaves. Energy Conversion and Management, v.46, p.1667-1679, 2005. https://doi.org/10.1016/j.enconman.2004.10.001

ISPN - Instituto Sociedade, População e Natureza. Boas práticas de manejo para o extrativismo sustentável da gueroba. Brasília: ISPN, 2013. 88p.

Lorenzi, H.; Souza, H. M.; Costa, J. T. M.; Cerqueira, L. S. C.; Ferreira, E. Palmeiras brasileiras e exóticas cultivadas. Nova Odessa: Instituto Plantarum, 2004. 416p.

Madureira, I. A.; Figueirêdo, R. M. F. de; Queiroz, A. J. de M.; Silva Filho, E. D. Cinética de secagem da polpa do figo-da-Índia. Revista Brasileira de Produtos Agroindustriais, v.13, p.345-354, 2011. https://doi.org/10.15871/1517-8595/rbpa.v13n4p345-354

Mophatara, D.; Rao, P. S. A thin layer drying model of parboiled wheat. Journal of Food Engineering, v.66, p.513-518, 2005. https://doi.org/10.1016/j.jfoodeng.2004.04.023

Moscon, E. S.; Martin, S.; Spehar, C. R.; Devilla, I. A.; Rodolfo Junior, F. Cinética de secagem de grãos de quinoa (Chenopodium quinoa W.). Revista Engenharia na Agricultura, v.25, p.318-328, 2017. https://doi.org/10.15038/reveng.v25n4.77

Oliveira, P. M. de; Oliveira, D. E. C. de; Resende, O.; Silva, D. V. Study of the drying mesocarp of baru (Dipteryx alata Vogel) fruits. Revista Brasileira de Engenharia Agrícola e Ambiental, v.22, p.872-877, 2018. https://doi.org/10.1590/1807-1929/agriambi.v22n12p872-877

Reis, D. R.; Brum, F. B.; Soares, E. J. O.; Magalhães, J. R.; Silva, F. S.; Porto, A. G. Drying kinetics of baru flours as function of temperature. Revista Brasileira de Engenharia Agrícola e Ambiental, v.22, p.713-719, 2018. https://doi.org/10.1590/1807-1929/agriambi.v22n10p713-719

Resende, O.; Oliveira, D. E. C. de; Costa, L. M.; Ferreira Junior, W. N. Drying kinetics of baru fruits (Dipteryx alata Vogel). Engenharia Agrícola, v.38, p.103-109, 2018. https://doi.org/10.1590/1809-4430-eng.agric.v38n1p103-109/2018

Santos, D. da C.; Leite, D. D. de F.; Lisbôa, J. F.; Ferreira, J. P. de L.; Santos, F. S. dos; Lima, T. L. B. de; Figueirêdo, R. M. F. de; Costa, T. N. da. Modelagem e propriedades termodinâmicas da secagem de fárias de acuri. Brazilian Journal of Food and Technology, v.22, p.1-12, 2019. https://doi.org/10.1590/1981-6723.03118

Silva, R. B. da; Silva, F. S. da; Porto, A. G.; Alves, A. P. Estudo da cinética de secagem da polpa de carambola. Revista Brasileira de Tecnologia Agroindustrial, v.10, p.2069-2080, 2016. https://doi.org/10.3895/rbta.v10n2.3261
Smaniotto, T. A. de S.; Resende, O.; Sousa, K. A. de; Oliveira, D. E. C. de; Campos, R. C. Drying kinetics of sunflower grains. Revista Brasileira de Engenharia Agrícola e Ambiental, v.21, p.203-208, 2017. https://doi.org/10.1590/1807-1929/agriambi.v21n3p203-208

Sousa, E. P. de; Figueirêdo, R. M. F. de; Gomes, J. P.; Queiroz, A. J. de M.; Castro, D. de S.; Lemos, D. M. Mathematical modeling of pequi pulp drying and effective diffusivity determination. Revista Brasileira de Engenharia Agrícola e Ambiental, v.21, p.493-498, 2017. https://doi.org/10.1590/1807-1929/agriambi.v21n7p493-498

Souza, D. G.; Resende, O.; Moura, L. C. de; Ferreira Junior, W. N.; Andrade, J. W. de S. Drying kinetics of the sliced pulp of biofortified sweet potato (Ipomoea batatas L.). Engenharia Agrícola, v.39, p.176-181, 2019. https://doi.org/10.1590/1809-4430-eng.agric.v39n2p176-181/2019

Zogzas, N. P.; Maroulis, Z. B.; Marinos-Kouris, D. Moisture diffusivity data compilation in foodstuffs. Drying Technology, v.14, p.2225-2253, 1996. https://doi.org/10.1080/07373939608917205