Original Article
Food Science and Technology
ISSN 0101-2061 (Print)
ISSN 1678-457X (Online)

DOI: https://doi.org/10.5327/fst.00169
CC BY

# Drying kinetics and mass transfer parameters of mung beans dried using a convective dryer

Valdiney Cambuy SIQUEIRA[1], Diogo Santos CRIPPA[1], Geraldo Acácio MABASSO[2*], Eduardo da Silva WESTEMAIER[1], Elton Aparecido Siqueira MARTINS[1], Vanderleia SCHOENINGER[1], Larissa Kathleen de CASTRO[1], Mariana Zampar TOLEDO[1]

**Abstract**

Convective drying of mung bean seeds was conducted to investigate drying kinetics and mass transfer parameters at temperatures of 40, 50, 60, 70, and 80°C and a fixed air velocity of 1.2 m $s^{-1}$. Drying characteristics were determined by drying rate, moisture ratio, diffusion coefficient, activation energy, Biot number, and mass transfer coefficient. Drying models such as Newton, Page, Henderson and Pabis, Logarithmic, Midilli, Two-term, and Diffusion approximation were applied and fitted to the moisture ratio of the experimental data. The drying rate was significantly affected by the drying temperature. The Midilli model was considered the most suitable for experimental drying curves. The effective moisture diffusivity ranged from $3.19\times10^{-9}$ to $10.76\times10^{-9}$ $m^2$ $s^{-1}$, with an activation energy of 59.78 kJ $mol^{-1}$. Similar to the mass transfer coefficient, the Biot number increased with increasing drying temperature. The simultaneous transfer of heat and mass was controlled by diffusion and surface.

**Keywords:** *Vigna radiata* L.; modeling; thin-layer drying kinetics; temperature.

**Practical Application:** Providing parameters for optimizing the drying process of the mung bean.

## 1 INTRODUCTION

Pulses, i.e., dried grain legumes, have attracted a lot of attention due to their low cost and nutritional characteristics (Hou et al., 2023). These legumes are usually rich in carbohydrates (55–65%) and proteins (21–26%), including essential amino acids, and have a low-fat content (1–4%) (Iriti & Varoni, 2017).

Mung bean stands out among the pulses, as it can be adjusted in different cultivation systems, providing an increase in income for small farmers (Keres et al., 2019). Recently, its production has expanded in Brazil, mainly in Cerrado areas, with the main objective of export (Favero et al., 2021).

Mung bean is a short-cycle crop (Khaket et al., 2015) and its grains have good nutritional characteristics (Yi-Shen et al., 2018), with 25–28% proteins (Khaket et al., 2015), which are easily digestible (Anwar et al., 2007; Yi-Shen et al., 2018). It also has a high content of phenolic acids and flavonoids, which are mainly linked to cell wall components (Ganesan & Xu, 2018), in addition to other components such as saponin, protease inhibitors, phytic acid, and fibers, which can promote health benefits (Muñoz et al., 2006), and high concentration of essential amino acids to meet the human body needs (Du et al., 2018). These conditions associated with a low cost make mung beans an invaluable source for those who cannot afford animal proteins (Hou et al., 2019).

Different processing techniques can be used to preserve the physical, chemical, and nutritional characteristics of foods, among which the drying process stands out. Drying is a crucial process for many grains and seeds (Moreno et al., 2022), as they are harvested with inadequate moisture content for conservation (Silva et al., 2018) and must undergo the drying process, which aims to remove excess water present in the product. Drying promotes the stability of foods for long periods because the reduction in moisture content leads to a reduction in the development of microorganisms and chemical degradation (Dhurve et al., 2022), increasing the shelf life of the product (Loan et al., 2023; Silva et al., 2015).

Hot air drying is preferred among all drying techniques (sun, infrared, hot air, vacuum, freezing, fluidized bed, and microwave drying) due to its simplicity, low cost, and higher efficiency compared with sun drying. Heating the drying air promotes the occurrence of moisture content gradients, influencing the uniformity of water diffusion in the product (Yang et al., 2013).

Simulating and obtaining theoretical information about the behavior of each product during water removal is relevant to the development and improvement of equipment used for drying grains (Siqueira et al., 2012). Knowledge of drying kinetics is fundamental in selecting suitable drying methods (Delfiya et al., 2022) and analyzing the complex phenomena of heat and mass transfer (Sahoo et al., 2022), contributing to the understanding of the phenomenon without the need for large-scale experiments, as it involves the drying of a thin layer of product. Thus, this research aimed to study the behavior of convective

*Received 24 Sept., 2023.*
*Accepted 20 Nov., 2023.*
[1]*Universidade Federal da Grande Dourados, Faculdade de Ciências Agrárias, Dourados, Mato Grosso do Sul, Brazil.*
[2]*Instituto Federal de Educação, Ciência e Tecnologia Goiano, Laboratório de Pós-Colheita de Produtos Vegetais, Rio Verde, Goiás, Brazil.*
*Corresponding author: geral.do@hotmail.com
Funding: Universidade Federal da Grande Dourados and National Council for Scientific and Technological Development.

drying in a thin layer of mung bean grains and determine the effective diffusivity and mass transfer parameters.

## 2 MATERIALS AND METHODS

### *2.1 Sample preparation*

Mung bean grains were harvested and manually threshed. They were then placed in polyethylene plastic bags in a cold chamber at 5°C to standardize the moisture content until the drying experiments were conducted. The moisture contents were determined in an oven at 105 ± 3°C for 24 h (Brasil, 2009).

### *2.2 Experiment setup and drying procedure*

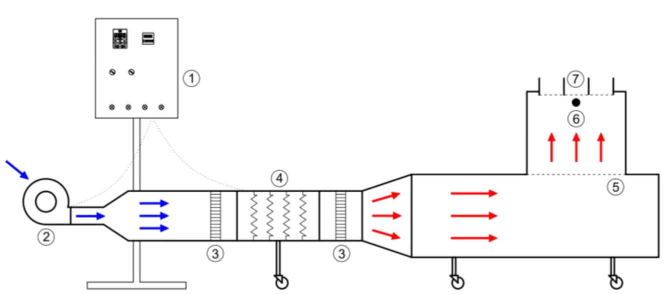
An experimental fixed-bed convective dryer (Figure 1) equipped with a system that precisely controls the flow and temperature of the drying air was used to study the drying kinetics of mung bean grains under different air conditions.

The heated and homogenized air is blown upward in the three trays at a constant velocity of 1.2 m $s^{-1}$. An amount of 0.2 kg of grains was evenly distributed in each tray, making a thin layer. Air temperature and velocity were controlled and monitored using a temperature controller (Novus, N1040) and a digital thermos-anemometer (Instrutherm AM-100).

The dryer was turned on 30 min before the experiment to stabilize the temperature in the trays. Drying was performed at five temperatures (Ts), that is, 40, 50, 60, 70, and 80°C. The water loss from the samples was recorded manually at time intervals that varied from 5 min for the first hour of drying, 10 min for the second and third hours, 20 min for the fourth hour, and thereafter 30 min until the end of the process, when a constant mass was reached. Subsequently, the seeds were placed in an oven at 105°C for 24 h to determine the final moisture content and dry matter.

### *2.3 Drying rate*

The drying rate (DR) of mung beans in a given time was calculated according to Equation 1 (Song et al., 2019):




1: Temperature and airflow control panel;
2: Centrifugal fan;
3: Air homogenizers;
4: Set of electrical resistances;
5: Perforated metal sheet for drying in thick layer;
6: Temperature measurement point;
7: Set of thin layer drying trays.

**Figure 1**. Experimental fixed-bed convective dryer used to dry mung bean grains.

$$DR = \frac{M_{t1} - M_{t2}}{t_2 - t_1} \quad (1)$$

where:

$M_{t1}$ and $M_{t2}$: the dry basis moisture content (kg water $kg^{-1}$ dry mass) at times $t_1$ and $t_2$, respectively.

### *2.4 Semi-empirical mathematical modeling*

Several semi-empirical models for predicting the drying behavior have been reported (Onwude et al., 2016). Seven of these models that were suitable for defining the drying behavior of seeds were chosen. Table 1 shows the list of these models.

The moisture ratio (MR) of seeds was estimated using Equation 2 (Malakar et al., 2021):

$$MR = \frac{M - M_e}{M_i - M_e} \quad (2)$$

where:

$M$: the moisture content at a given instance $t$;

$M_i$: the initial moisture content;

$M_e$: the equilibrium moisture content.

The experimentally estimated MR was fitted in different models shown in Table 1 to identify the best fit for the thin layer drying behavior of seeds under different drying conditions.

The model parameters were estimated by non-linear regression. The mean relative error (MRE) and the reduced chi-square parameter ($\chi^2$) were used as a criterion for selecting the best model to represent seed drying kinetics, according to Equations 10 and 11, respectively:

$$MRE = \frac{100}{N} \sum_{i=1}^{N} \left( \frac{\left| Y_{exp,i} - Y_{pre,i} \right|}{Y_{exp,i}} \right) \quad (10)$$

$$\chi^2 = \frac{\sum_{i=1}^{N} \left( Y_{exp,i} - Y_{pre,i} \right)^2}{N - z} \quad (11)$$

**Table 1**. Semi-empirical models for describing the drying kinetics.

| Models | Model equation | |
|---|---|---|
| Newton | $MR = \exp(-k\,t)$ | (3) |
| Page | $MR = \exp(-k\,t^n)$ | (4) |
| Henderson and Pabis | $MR = a \exp(-k\,t)$ | (5) |
| Logarithmic | $MR = a \exp(-k\,t) + c$ | (6) |
| Midilli | $MR = a \exp(-k\,t^n) + b\,t$ | (7) |
| Two terms | $MR = -a \exp(-k_0\,t) + b \exp(-k_1\,t)$ | (8) |
| Diffusion approximation | $MR = a \exp(-k\,t) + (1 - a) \exp(-k\,b\,t)$ | (9) |

t: the drying time; h, k, $k_0$, and $k_1$: drying constants; a, b, c, and n: the coefficients of the models.

where:

$Y_{exp}$ and $Y_{pre}$: the experimental and predicted values, respectively, for either moisture content;

*N*: the total number of observations;

*z*: the number of constants.

Akaike information criterion (AIC) and Schwarz's Bayesian information criterion (BIC) were used as decisive criteria in choosing the model that best fitted the experimental data among those that were satisfactory regarding the parameter MRE. AIC and BIC were calculated according to Equations 12 and 13, respectively:

$$AIC\ L = -2 \log L + 2p \tag{12}$$

$$BIC\ L = -2 \log L + p \ln (N - r_m) \tag{13}$$

where:

L: the maximum likelihood;

p: the number of parameters of the model;

N: the total number of observations;

$r_m$: the rank of the matrix X (incidence matrix for fixed effects).

### *2.5 Mass transfer parameters*

#### *2.5.1 Diffusion coefficient and activation energy*

The effective diffusivity was determined using the liquid diffusion model for the spherical geometric shape, with an eight-term approximation (Equation 14), fitted to the experimental drying data of mung bean. Negligible shrinkage after drying and moisture content were assumed to be evenly distributed:

$$MR = \frac{6}{\pi^2} \sum_{n_t=1}^{\infty} \frac{1}{n_t^2} \exp\left[\frac{n_t^2\ \pi^2\ D_{eff}\ t}{9} \left(\frac{3}{r}\right)^2\right] \tag{14}$$

where:

t: the drying time;

$D_{eff}$: the liquid diffusion coefficient ($m^2\ s^{-1}$);

r: the equivalent radius (0.00227 m);

$n_t$: the number of terms.

The equivalent-sphere radius was determined using Equation 15:

$$r = \sqrt[3]{\frac{3\ \pi \left(\frac{a\ b\ c}{6}\right)}{4\ \pi}} \tag{15}$$

Where:

a: the seed's longest axis;

b: the seed's middle axis;

c: the seed's shortest axis.

The relationship between the increase in the effective diffusion coefficient and the elevation of the drying air temperature was described by the Arrhenius equation (Equation 16):

$$D_{eff} = D_0 \exp\left(\frac{E_a}{R\ T_a}\right) \tag{16}$$

Where:

$D_0$: the pre-exponential factor ($m^2\ s^{-1}$);

R: the universal gas constant (8,314 kJ $kmol^{-1}\ K^{-1}$);

Ta: the temperature (K);

$E_a$: the activation energy (kJ $mol^{-1}$).

#### *2.5.2 Biot number and convective mass transfer coefficient*

The mass transfer coefficient states the resistance offered to moisture transport from the food material to the drying medium and can be expressed as shown in Equations 17–19 (Dhurve et al., 2021):

$$h_m = \frac{D_{eff}\ x\ B_i}{H} \tag{17}$$

$$B_i = \frac{24.848}{D_i^{0.375}} \tag{18}$$

$$D_i = \frac{v}{kH} \tag{19}$$

Where:

$h_m$: the convective mass transfer coefficient (m $s^{-1}$);

$B_i$: the Biot number;

$D_i$: the Dincer number; v is the air velocity (m $s^{-1}$);

*H*: the seed thickness (m);

*k*: the drying constant, consisting of statistical indicators taken from the best-fitted model.

## 3 RESULTS AND DISCUSSION

The time required to reduce the moisture content from approximately 34 to 11% (wb) was 11-1.3 h (Figure 2). The lowest drying times were obtained when higher temperatures were used. A similar behavior was observed in the drying of other bean species (Junqueira et al., 2018; Maia et al., 2019; Quequeto et al., 2017). A higher partial pressure of water vapor in the product

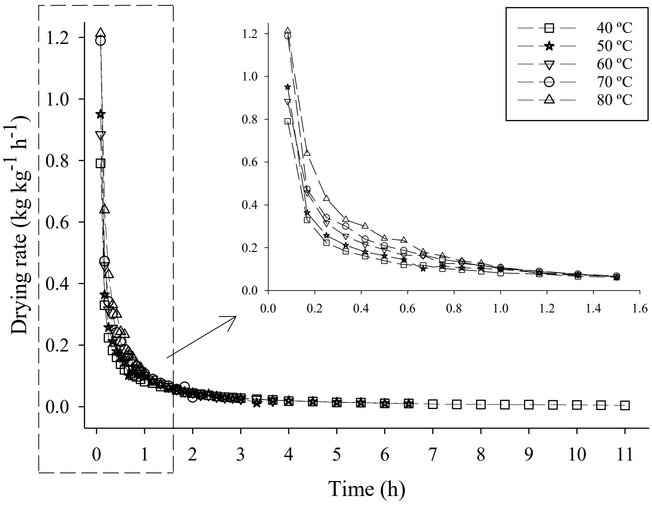



**Figure 2**. Drying rate for mung bean grains during the drying process.

was observed at higher temperatures, which increased the drying speed, especially at the beginning of the process (Jiang et al., 2022; Siqueira et al., 2020a). The drying rate decreased over time, as the internal transfer of water mass in the form of steam to the periphery of the product was not compensated by the evaporation rate from the surface. Morais et al. (2013) found a similar behavior.

The drying curve has a steep downward slope, assuming that the process started already in the first period of decreasing drying rate. The rate reduces significantly after 20 min, moving on to the other phases, i.e., the second and third periods. Only the flow in the vapor phase prevails in the end.

The best model for describing the drying kinetics of mung bean was chosen, considering mean relative error values lower than 10% (Mohapatra & Rao, 2005) and low chi-square values (Dhurve et al., 2022; Midilli & Kucuk, 2003). Considering these criteria, the models that presented the best adjustments for all the studied air conditions were the Page, logarithmic, Midilli, and two-term models (Table 2).

**Table 2**. Statistical constant and indicators of the fitted model in experimental data of drying mung beans.

| Model | Temperature (°C) | Constant | MRE | $\chi^2$ |
|---|---|---|---|---|
| Newton | 40 | k = 0.4617 | 36.319 | 1.25E-02 |
| | 50 | k = 0.5791 | 29.277 | 1.19E-02 |
| | 60 | k = 0.7315 | 22.949 | 8.65E-03 |
| | 70 | k = 1.0511 | 18.656 | 7.10E-03 |
| | 80 | k = 1.4564 | 12.995 | 4.17E-03 |
| Page | 40 | k = 0.6425; n = 0.5153 | 2.482 | 5.67E-05 |
| | 50 | k = 0.7279; n = 0.5199 | 1.692 | 3.90E-05 |
| | 60 | k = 0.8133; n = 0.5722 | 1.732 | 5.86E-05 |
| | 70 | k = 0.9934; n = 0.5826 | 0.760 | 1.22E-05 |
| | 80 | k = 1.2362; n = 0.6487 | 1.066 | 2.90E-05 |
| Hendereson and Pabis | 40 | k = 0.2707; a = 0.7576 | 18.509 | 4.33E-03 |
| | 50 | k = 0.3678; a = 0.7705 | 11.114 | 3.15E-03 |
| | 60 | k = 0.5250; a = 0.8124 | 11.505 | 3.31E-03 |
| | 70 | k = 0.7959; a = 0.8346 | 10.111 | 3.04E-03 |
| | 80 | k = 1.2281; a = 0.8868 | 8.154 | 2.27E-03 |
| Logarithmic | 40 | k = 0.5841; a = 0.6832. b = 0.1681 | 7.549 | 1.17E-03 |
| | 50 | k = 0.8682; a = 0.6675; b = 0.2039 | 6.387 | 1.09E-03 |
| | 60 | k = 1.2550; a = 0.6949; b = 0.2241 | 4.490 | 6.39E-04 |
| | 70 | k = 1.7817; a = 0.6956; b = 0.2303 | 4.380 | 7.68E-04 |
| | 80 | k = 2.5483; a = 0.7255; b = 0.2355 | 3.173 | 4.31E-04 |
| Midilli | 40 | k = 0.6511; n = 0.5485; a = 1.0002; b = 0.0037 | 0.677 | 4.51E-06 |
| | 50 | k = 0.7461; n = 0.5616; a = 0.9973; b = 0.0071 | 0.883 | 1.21E-05 |
| | 60 | k = 0.8731; n = 0.6265; a = 1.0025; b = 0.0169 | 0.475 | 4.45E-06 |
| | 70 | k = 1.0229; n = 0.6049; a = 0.9988; b = 0.0089 | 0.398 | 5.61E-06 |
| | 80 | k = 1.3718; n = 0.7029; a = 0.9995; b = 0.0379 | 0.451 | 6.37E-06 |
| Two terms | 40 | k = 1.6416; a = 0.4416; b = 0.4905; g = 0.1420 | 3.736 | 3.19E-04 |
| | 50 | k = 2.3813; a = 0.4191; b = 0.5252; g = 0.2049 | 3.364 | 3.42E-04 |
| | 60 | k = 3.3303; a = 0.3951; b = 0.5799; g = 0.3220 | 2.135 | 1.37E-04 |
| | 70 | k = 6.1188; a = 0.3452; b = 0.6411; g = 0.5336 | 2.106 | 1.53E-04 |
| | 80 | k = 7.1005; a = 0.3308; b = 0.6638; g = 0.8167 | 1.752 | 8.09E-05 |
| Diffusion approximation | 40 | k = 2.3313; a = 0.4653; b = 0.0678 | 5.449 | 4.92E-04 |
| | 50 | k = 3.3867; a = 0.4277; b = 0.0681 | 4.749 | 4.47E-04 |
| | 60 | k = 3.8782; a = 0.3995; b = 0.0869 | 2.515 | 1.61E-04 |
| | 70 | k = 6.6311; a = 0.3511; b = 0.0818 | 2.221 | 1.55E-04 |
| | 80 | k = 7.3626; a = 0.3314; b = 0.1119 | 1.761 | 4.86E-03 |

Thus, a complementary analysis, such as AIC and BIC, becomes relevant to define the model that best describes each drying condition (Table 3) or even represents all the studied conditions.

AIC and BIC used only the four models that best met the MRE and $\chi^2$ assumptions. The Midilli model best fitted the drying of mung bean grains, as the lower the AIC and BIC values, the better the fit of the model to the experimental data (Wolfinger, 1993). According to this author, AIC and BIC could assist the selection process of the pre-selected models according to the Gauss-Newton criterion.

The drying rate constant (k) of the chosen model increased as expected with increasing drying temperature (Table 2). A similar k behavior was observed for the drying of buckwheat grains (Siqueira et al., 2020a), in which this parameter was related to the effective diffusivity of drying in the falling-rate period and could be used to partially explain the behavior of the drying air temperature. The experimental and predicted MRE values were compared to validate the Midilli model (Figure 3). There is a high degree of proximity between the data, characterizing the excellent fit of the model to the experimental values.

Table 4 presents the estimated values of diffusion coefficient, activation energy, Biot number, and convective mass transfer coefficient of mung beans. The effective diffusivity of the grains increased with increasing temperature. The higher the temperature, the lower the viscosity and the higher the agitation of water molecules, promoting greater fluidity in the capillaries of the product. A similar behavior was observed for grape seeds (Roberts et al., 2008), soybeans (Silva et al., 2020), and cowpeas (Morais et al., 2013). The Deff values in this research were in the general range from $10^{-11}$ to $10^{-9}$ $m^2$ $s^{-1}$ for agricultural products (Madamba et al., 1996).

The activation energy (Ea) value for drying mung bean was 59.78 kJ $mol^{-1}$. It can be considered an intermediate value, as the variation range is 12.7–110.0 kJ $mol^{-1}$ for most food products (Zogzas et al., 1996). A lower activation energy corresponds to easy moisture removal from the material subjected to drying (Kosasih et al., 2020) because the activation energy is the energy barrier that must be overcome to start the mass diffusion from the wet material (Li et al., 2019; Xie et al., 2017), and variations are commonly found, as it can be influenced by the shape of the product, initial and final moisture content, chemical composition, structure, and the imposed drying conditions (Siqueira et al., 2020b).

The Biot number (Bi) determines the rate of mass diffusion during the drying process of food products (Dhurve et al., 2022). An increase in Bi was observed with increasing temperature, and the values ranged from 2.612 to 3.454. Different reports have indicated that drying occurs by diffusion and controlled surface when the Bi value is lower than 30 (Barati & Esfahani, 2013). Similar trends were observed in paddy (Golpour et al., 2021) and pumpkin seeds (Dhurve et al., 2021).

The hm values obtained for mung bean seeds at different temperatures increased with increasing drying temperature.

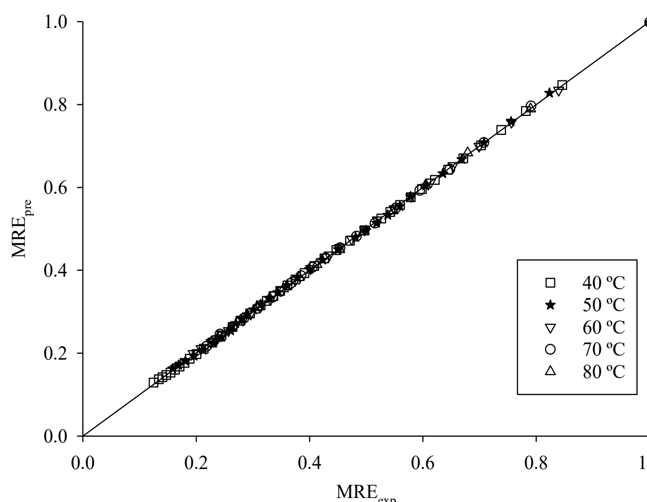



**Figure 3**. Validation of experimental moisture ratio ($MRE_{exp}$) versus predicted moisture ratio ($MRE_{pre}$).

**Table 3**. Akaike information criterion (AIC) and Schwarz's Bayesian information criterion (BIC) for the models that best fit the drying data.

| Model | 40°C | | 50°C | | 60°C | | 70°C | | 80°C | |
|---|---|---|---|---|---|---|---|---|---|---|
| | AIC | BIC | AIC | BIC | AIC | BIC | AIC | BIC | AIC | BIC |
| Page | -280 | -275 | -221 | -217 | -172 | -169 | -155 | -152 | -104 | -102 |
| Logarithmic | -155 | -149 | -128 | -122 | -118 | -112 | -81 | -77 | -69 | -66 |
| Midilli | -382 | -374 | -260 | -253 | -211 | -204 | -156 | -152 | -116 | -113 |
| Two terms | -208 | -199 | -163 | -155 | -158 | -152 | -113 | -108 | -90 | -86 |

**Table 4**. Values of the diffusion coefficient ($D_{eff}$), activation energy ($E_a$), Biot number ($B_i$), and convective mass transfer coefficient ($h_m$) of mung beans under different drying conditions.

| Drying temperature (°C) | $D_{eff}$ ($m^2$ $s^{-1}$) | Ea (kJ $mol^{-1}$) | $B_i$ | $h_m$ (m $s^{-1}$) |
|---|---|---|---|---|
| 40 | $3.196 \times 10^{-11}$ | | 2.612 | $1.84 \times 10^{-8}$ |
| 50 | $4.185 \times 10^{-11}$ | | 2.749 | $2.54 \times 10^{-8}$ |
| 60 | $5.409 \times 10^{-11}$ | 59.78 | 2.916 | $3.48 \times 10^{-8}$ |
| 70 | $7.744 \times 10^{-11}$ | | 3.094 | $5.28 \times 10^{-8}$ |
| 80 | $10.76 \times 10^{-11}$ | | 3.454 | $8.19 \times 10^{-8}$ |

Drying at higher temperatures causes an increase in the activity of water molecules, resulting in higher mass transfer rates (Darvishi et al., 2017).

## 4 CONCLUSION

This study investigated the drying kinetics and mass transfer parameters of mung beans. The drying rate was characterized as a period of decreasing ratio, which was highly influenced by air conditions. The increase in temperature promoted faster drying of grains. The Midilli model accurately predicted the drying behavior of mung beans. $D_{eff}$ ranged from 3.196 to 10.76 ´ $10^{-9}$ $m^2$ $s^{-1}$, with an activation energy of 59.78 kJ $mol^{-1}$. The Biot number and mass transfer coefficient increased with increasing drying temperature. The highest values of the diffusion coefficient and mass transfer parameters were observed at 80°C, which is the recommended temperature for drying mung bean, as it provides a shorter process time. However, we suggest an in-depth study of the influence of this condition on nutritional compounds.

## REFERENCES


Anwar, F., Latif, S., Przybylski, R., Sultana, B., & Ashraf, M. (2007). Chemical composition and antioxidant activity of seeds of different cultivars of mungbean. *Journal of Food Science*, *72*(7), S503-S510. https://doi.org/10.1111/J.1750-3841.2007.00462.X

Barati, E., & Esfahani, J. A. (2013). A novel approach to evaluate the temperature during drying of food products with negligible external resistance to mass transfer. *Journal of Food Engineering*, *114*(1), 39-46. https://doi.org/10.1016/J.JFOODENG.2012.07.028

Brasil (2009). *Regras para análise de sementes*. Ministério da Agricultura Pecuária e Abastecimento.

Darvishi, H., Farhudi, Z., & Behroozi-Khazaei, N. (2017). Mass transfer parameters and modeling of hot air drying kinetics of dill leaves. *Chemical Product and Process Modeling*, *12*(2), 1-15. https://doi.org/10.1515/CPPM-2015-0079

Delfiya, D. S. A., Prashob, K., Murali, S., Alfiya, P. V., Samuel, M. P., & Pandiselvam, R. (2022). Drying kinetics of food materials in infrared radiation drying: A review. *Journal of Food Process Engineering*, *45*(6), e13810. https://doi.org/10.1111/JFPE.13810

Dhurve, P., Kumar Arora, V., Kumar Yadav, D., & Malakar, S. (2022). Drying kinetics, mass transfer parameters, and specific energy consumption analysis of watermelon seeds dried using the convective dryer. *Materials Today: Proceedings*, *59*(Part 1), 926-932. https://doi.org/10.1016/J.MATPR.2022.02.008

Dhurve, P., Tarafdar, A., & Arora, V. K. (2021). Vibro-fluidized bed drying of pumpkin seeds: Assessment of mathematical and artificial neural network models for drying kinetics. *Journal of Food Quality*, *2021*, 7739732. https://doi.org/10.1155/2021/7739732

Du, M., Xie, J., Gong, B., Xu, X., Tang, W., Li, X., Li, C., & Xie, M. (2018). Extraction, physicochemical characteristics and functional properties of Mung bean protein. *Food Hydrocolloids*, *76*, 131-140. https://doi.org/10.1016/J.FOODHYD.2017.01.003

Favero, V. O., Carvalho, R. H. de, Leite, A. B. C., Freitas, K. M. de, Zilli, J. É., Xavier, G. R., Rumjanek, N. G., & Urquiaga, S. (2021). Characterization and nodulation capacity of native bacteria isolated from mung bean nodules used as a trap plant in Brazilian tropical soils. *Applied Soil Ecology*, *167*, 104041. https://doi.org/10.1016/J.APSOIL.2021.104041

Ganesan, K., & Xu, B. (2018). A critical review on phytochemical profile and health promoting effects of mung bean (*Vigna radiata*). *Food Science and Human Wellness*, *7*(1), 11-33. https://doi.org/10.1016/J.FSHW.2017.11.002

Golpour, I., Guiné, R. P. F., Poncet, S., Golpour, H., Amiri Chayjan, R., & Amiri Parian, J. (2021). Evaluating the heat and mass transfer effective coefficients during the convective drying process of paddy (*Oryza sativa* L.). *Journal of Food Process Engineering*, *44*(9), e13771. https://doi.org/10.1111/JFPE.13771

Hou, D., Feng, Q., Niu, Z., Wang, L., Yan, Z., & Zhou, S. (2023). Promising mung bean proteins and peptides: A comprehensive review of preparation technologies, biological activities, and their potential applications. *Food Bioscience*, *55*, 102972. https://doi.org/10.1016/J.FBIO.2023.102972

Hou, D., Yousaf, L., Xue, Y., Hu, J., Wu, J., Hu, X., Feng, N., & Shen, Q. (2019). Mung Bean (*Vigna radiata* L.): Bioactive Polyphenols, Polysaccharides, Peptides, and Health Benefits. *Nutrients*, *11*(6), 1238. https://doi.org/10.3390/NU11061238

Iriti, M., & Varoni, E. M. (2017). Pulses, healthy, and hustainable hood sources for feeding the planet. *International Journal of Molecular Sciences*, *18*(2), 255. https://doi.org/10.3390/IJMS18020255

Jiang, N., Ma, J., Ma, R., Zhang, Y., Chen, P., Ren, M., & Wang, C. (2022). Effect of slice thickness and hot-air temperature on the kinetics of hot-air drying of Crabapple slices. *Food Science and Technology*, *43*, e100422. https://doi.org/10.1590/FST.100422

Junqueira, M. H., Siqueira, V. C., Schoeninger, V., Hartmann Filho, C. P., Quequeto, W., Leite, R. A., & Pereira, C. G. (2018). Desempenho de plântulas de sementes de feijão BRS Estilo submetidas a diferentes temperaturas de secagem. *Global Science and Technology*, *11*(2), 304-314.

Keres, G., Silva, E. C. da, Olibone, D., Pivetta, L. G., & Olibone, A. P. E. (2019). Desempenho de feijoeiro mungo em densidades populacionais e espaçamento entre linhas no Mato Grosso. *Scientia Agraria Paranaensis*, *18*(3), 251-258. https://doi.org/https://doi.org/10.18188/sap.v18i3.22379

Khaket, T. P., Dhanda, S., Jodha, D., & Singh, J. (2015). Purification and biochemical characterization of dipeptidyl peptidase-II (DPP7) homologue from germinated *Vigna radiata* seeds. *Bioorganic Chemistry*, *63*, 132-141. https://doi.org/10.1016/J.BIOORG.2015.10.004

Kosasih, E. A., Zikri, A., & Dzaky, M. I. (2020). Effects of drying temperature, airflow, and cut segment on drying rate and activation energy of elephant cassava. *Case Studies in Thermal Engineering*, *19*, 100633. https://doi.org/10.1016/J.CSITE.2020.100633

Li, H., Xie, L., Ma, Y., Zhang, M., Zhao, Y., & Zhao, X. (2019). Effects of drying methods on drying characteristics, physicochemical properties and antioxidant capacity of okra. *LWT - Food Science and Technology*, *101*, 630-638. https://doi.org/10.1016/J.LWT.2018.11.076

Loan, L. T. K., Thuy, N. M., & Tai, N. V. (2023). Mathematical and artificial neural network modeling of hot air drying kinetics of instant "Cẩm" brown rice. *Food Science and Technology*, *43*, e27623. https://doi.org/10.5327/FST.27623

Madamba, P. S., Driscoll, R. H., & Buckle, K. A. (1996). The thin-layer drying characteristics of garlic slices. *Journal of Food Engineering*, *29*(1), 75-97. https://doi.org/10.1016/0260-8774(95)00062-3

Maia, R. B., Santos, S. G. F., Queiroz, J. S., Rodovalho, R. S., & Silva, D. P. (2019). Drying kinetics and thermodynamic properties of pigeon pea beans. *Científica*, *47*(2), 164-174. https://doi.org/10.15361/1984-5529.2019V47N2P164-174

Malakar, S., Arora, V. K., & Nema, P. K. (2021). Design and performance evaluation of an evacuated tube solar dryer for drying garlic clove. *Renewable Energy*, *168*, 568-580. https://doi.org/10.1016/J.RENENE.2020.12.068

Midilli, A., & Kucuk, H. (2003). Mathematical modeling of thin layer drying of pistachio by using solar energy. *Energy Conversion and Management*, *44*(7), 1111-1122. https://doi.org/10.1016/S0196-8904(02)00099-7

Mohapatra, D., & Rao, P. S. (2005). A thin layer drying model of parboiled wheat. *Journal of Food Engineering*, *66*(4), 513-518. https://doi.org/10.1016/J.JFOODENG.2004.04.023

Morais, S. J. da S., Devilla, I. A., Ferreira, D. A., & Teixeira, I. R. (2013). Mathematical modeling of the drying curves and diffusion coefficient of cowpea grains (*Vigna unguiculata* (L.) Walp.). *Revista Ciência Agronômica*, *44*(3), 455-463. https://doi.org/10.1590/S1806-66902013000300006

Moreno, Á. H., Aguirre, Á. J., Hernández Maqueda, R., Jiménez Jiménez, G., & Torres Miño, C. (2022). Effect of temperature on the microwave drying process and the viability of amaranth seeds. *Biosystems Engineering*, *215*, 49-66. https://doi.org/10.1016/J.BIOSYSTEMSENG.2021.12.019

Muñoz, M., Ancos, B. de, Sánchez-Moreno, C., & Cano, M. P. (2006). Evaluation of chemical and physical (high-pressure and temperature) treatments to improve the safety of minimally processed mung bean sprouts during refrigerated storage. *Journal of Food Protection*, *69*(10), 2395-2402. https://doi.org/10.4315/0362-028X-69.10.2395

Onwude, D. I., Hashim, N., & Chen, G. (2016). Recent advances of novel thermal combined hot air drying of agricultural crops. *Trends in Food Science & Technology*, *57*(Part A), 132-145. https://doi.org/10.1016/J.TIFS.2016.09.012

Quequeto, W. D., Siqueira, V. C., Ferranti, L. F., Schoeninger, V., & Leite, R. A. (2017). Cinética de secagem dos grãos de feijão cultivar IPR Tangará. *Energia na Agricultura*, *32*(4), 408-415. https://doi.org/10.17224/EnergAgric.2017v32n4p408-415

Roberts, J. S., Kidd, D. R., & Padilla-Zakour, O. (2008). Drying kinetics of grape seeds. *Journal of Food Engineering*, *89*(4), 460-465. https://doi.org/10.1016/J.JFOODENG.2008.05.030

Sahoo, M., Titikshya, S., Aradwad, P., Kumar, V., & Naik, S. N. (2022). Study of the drying behaviour and color kinetics of convective drying of yam (*Dioscorea hispida*) slices. *Industrial Crops and Products*, *176*, 114258. https://doi.org/10.1016/J.INDCROP.2021.114258

Silva, F. P. da, Siqueira, V. C., Quequeto, W. D., Junqueira, M. H., & Goneli, A. L. D. (2018). Propriedades físicas dos grãos de niger. *Revista Engenharia na Agricultura*, *26*(6), 507-515. https://doi.org/10.13083/reveng.v26i6.864

Silva, L. P., Santos, S. G. F., Queiroz, J. S., Rodovalho, R. S., & Buso, W. H. D. (2020). Drying kinetics of soybean grains. *Científica*, *48*(2), 99-106. https://doi.org/10.15361/1984-5529.2020V48N2P99-106

Silva, W. P. da, Rodrigues, A. F., Silva, C. M. D. P. S. e, Castro, D. S. de, & Gomes, J. P. (2015). Comparison between continuous and intermittent drying of whole bananas using empirical and diffusion models to describe the processes. *Journal of Food Engineering*, *166*, 230-236. https://doi.org/10.1016/J.JFOODENG.2015.06.018

Siqueira, V. C., Leite, R. A., Mabasso, G. A., Martins, E. A. S., Quequeto, W. D., & Isquierdo, E. P. (2020a). Drying kinetics and effective diffusion of buckwheat grains. *Ciência e Agrotecnologia*, *44*, e011320. https://doi.org/10.1590/1413-7054202044011320

Siqueira, V. C., Mabasso, G. A., Quequeto, W. D., Silva, C. R. da, Martins, E. A. S., & Isquierdo, E. P. (2020b). Drying kinetics and effective diffusion of watermelon seeds. *Research, Society and Development*, *9*(4), e16942887. https://doi.org/10.33448/RSD-V9I4.2887

Siqueira, V. C., Resende, O., & Chaves, T. H. (2012). Drying kinetics of jatropha seeds. *Revista Ceres*, *59*(2), 171-177. https://doi.org/10.1590/S0034-737X2012000200004

Song, X. D., Mujumdar, A. S., Law, C. L., Fang, X. M., Peng, W. J., Deng, L. Z., Wang, J., & Xiao, H. W. (2019). Effect of drying air temperature on drying kinetics, color, carotenoid content, antioxidant capacity and oxidation of fat for lotus pollen. *Drying Technology*, *38*(9), 1151-1164. https://doi.org/10.1080/07373937.2019.1616752

Wolfinger, R. (1993). Covariance structure selection in general mixed models. *Communications in Statistics*, *22*(4), 1079-1106. https://doi.org/10.1080/03610919308813143

Xie, L., Mujumdar, A. S., Fang, X. M., Wang, J., Dai, J. W., Du, Z. L., Xiao, H. W., Liu, Y., & Gao, Z. J. (2017). Far-infrared radiation heating assisted pulsed vacuum drying (FIR-PVD) of wolfberry (*Lycium barbarum* L.): Effects on drying kinetics and quality attributes. *Food and Bioproducts Processing*, *102*, 320-331. https://doi.org/10.1016/J.FBP.2017.01.012

Yang, Z., Zhu, E., Zhu, Z., Wang, J., & Li, S. (2013). A comparative study on intermittent heat pump drying process of Chinese cabbage (*Brassica campestris* L.ssp) seeds. *Food and Bioproducts Processing*, *91*(4), 381-388. https://doi.org/10.1016/J.FBP.2013.02.006

Yi-Shen, Z., Shuai, S., & Fitzgerald, R. (2018). Mung bean proteins and peptides: nutritional, functional and bioactive properties. *Food and Nutrition*, *62*, 1-11. https://doi.org/10.29219%2Ffnr.v62.1290

Zogzas, N. P., Maroulis, Z. B., & Marinos-Kouris, D. (1996). Moisture diffusivity data compilation in foodstuffs. *Drying Technology*, *14*(10), 2225-2253. https://doi.org/10.1080/07373939608917205