Kinetics of drying of paddy rice grains at different temperatures using dry and wet firewood as fuel

Maurício Albertoni Scariot*, Bruna Rohrig, Rafael Stefanhak Barok, Rafael Gomes Dionello, Lauri Lourenço Radünz

(Departamento de Fitossanidade, Universidade Federal do Rio Grande do Sul – UFRGS – Faculdade de Agronomia, Avenida Bento Gonçalves, 7712, CEP 91540-000 Porto Alegre, RS, Brazil)

Abstract: The objective of this work was to test the fitness of different empirical and semi-empirical models to the experimental data obtained from the intermittent drying of paddy rice grains. Rice grains, cultivar IRGA 424 RI, were dried in a cross-flow dryer with static capacity for 580 kg of paddy rice in intermittent operation with a 1:1 ratio (drying time and equalization time). Drying air temperatures of 55ºC and 65ºC were used, using dry and wet *Eucalyptus* sp. firewood as fuel, with moisture contents of 12% and 32%, respectively. Every 30 minutes, during the drying process, the temperature and relative humidity of the ambient air were collected, as well as the inlet and outlet air temperature of the dryer, in addition to the moisture content and the temperature of the grain mass. Twelve empirical models were tested by applying non-linear regressions by the Gauss-Newton method, with the models parameter values being estimated as a function of drying air temperature and firewood moisture content. The empirical model proposed by Midilli showed the best fitness to describe the intermittent drying of paddy rice grains at different drying air temperatures and using dry and wet firewood as fuel.

Keywords: *Oryza sativa* L., Removal of water, Empirical models, Midilli

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1 Introduction

Rice (*Oryza sativa* L.) is one of the main crops produced in Brazil and in the world. The world production of rice in the 2020/21 crop was 504.4 million tons, with a sown area of 162.4 million hectares and average yield of 4,662 kg ha^{-1} (USDA, 2021). In Brazil, total rice production for the 2020/21 crop was 11.6 million tons, with a sown area of 1.7 million hectares and average yield of 6,905 kg ha^{-1} (CONAB, 2021).

Drying is an important process for maintaining of grain quality after harvesting, as it allows for a moisture content reduction and, consequently, storage for a longer period of time. During drying, the water removal from the grains happens through a process of simultaneous transfer of heat and mass between the drying air and the grains (Afonso Júnior and Corrêa, 1999). However, drying must be carried out with care, as it can compromise the grains quality when done wrongly, especially in the drying air temperature management, which is one of the main factors responsible for the speed and quality of the process.

In Brazil, the grain drying is mostly done artificially, with the help of dryers that use biomass as fuel, mainly firewood (Resende, 2021). However, during the furnaces operation for heating the drying air, the combustion

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* **Corresponding author: Maurício Albertoni Scariot,** PhD student, Programa de Pós Graduação em Fitotecnia, Universidade Federal do Rio Grande do Sul, Brazil. Email: mauricioalbertoniscariot@gmail.com. Tel: (51) 3308-6001.

quality can be negatively influenced by the material moisture used as fuel, since, initially, a large part of the energy is required for the water evaporation, reducing the fuel calorific value (Simoneit, 2002).

The study of the water removal process in a product during the drying, through mathematical modeling, is extremely important for the development and improvement of equipment used for drying (Cihan et al., 2007; Goneli et al., 2007). The mathematical models used to describe the drying process of agricultural products can be theoretical, which only consider the internal resistance to heat and water transfer between the product and the hot air, in addition to semi-theoretical and empirical models, which considered only the external resistance to temperature and relative humidity of the drying air (Midilli et al., 2002).

The use of empirical and semi-empirical models is due to their simplicity and easy application (Cihan et al., 2007). Some works have already studied the application of empirical models to describe the drying of paddy rice grains, such as Cihan et al. (2007) and Meneghetti et al. (2012) to describe intermittent drying of rice grains, Khanali et al. (2012) and Pattanayak et al. (2019) to describe fluidized bed drying of rice grains at different temperatures and Hacıhafızoğlu et al. (2008) to describe the drying of thin layer rice grains using different temperatures.

The objective of the study was to test the fitness of different empirical and semi-empirical models to the experimental data obtained from intermittent drying of paddy rice grains, carried out at different drying air temperatures and using dry and wet firewood as fuel.

2 Material and methods

The experiment was carried out at the Agronomic Experimental Station of the Federal University of Rio Grande do Sul (UFRGS). Rice grains, cultivar IRGA 424 RI, were obtained by irrigated cultivation in the experimental area of the Instituto Rio-Grandense do Arroz (IRGA) in the 2018 season.

The harvest was carried out with the aid of a self-propelled harvester, when the grains had a moisture content of approximately 22% in wet basis. After harvesting, the grains were subjected to pre-cleaning in an air and sieves machine until they reached an impurity content of less than 1%.

The grains drying was carried out in a cross-flow drier, with static capacity for 580 kg of paddy rice and operating under a 1:1 intermittent system (time in the drying chamber: time in the equalization chamber), until the grains reached moisture content of approximately 12% in wet basis. Drying air temperatures of 55ºC and 65ºC were used, using *Eucalyptus* sp. firewood up to 20 cm in diameter and 40 cm in length as fuel, with different moisture contents (12% and 32% in dry basis). The firewood moisture content as determined, on a dry basis (d.b), by the oven method at 103ºC±3ºC until constant weight, as described by Gatto et al. (2003).

The drying process was carried out in duplicate, with maximum dryer load for each condition studied (temperature x firewood moisture content). The dryings were carried out randomly, with the furnace and dryer being awaited to cool down for subsequent drying. Every 30 minutes, throughout the drying process, the temperature and relative humidity of the air were collected, with the aid of a digital thermo-hygrometer, and the inlet and outlet air temperature of the dryer, with the aid of a mercury thermometer, installed in the dryer. In addition, the grain mass temperature was determined by collecting 500 g of grains at the dryer outlet, which were immediately placed in a Styrofoam container, and the temperature was measured with a mercury thermometer, after two minutes. The grains moisture content was determined, on a wet basis (w.b), by the indirect method with a dielectric moisture meter (Gehaka® G650), with subsequent confirmation by the oven method at 105ºC±3ºC for 24 h (Brasil, 2009). In addition, using psychrometric equations, the relative humidity of the drying air was calculated.

For the mathematical models application, the moisture content ratio (MR) was calculated according to the following equation:

$$MR = \frac{M - Me}{Mi - Me} \tag{1}$$

Where: MR = moisture ratio;

M = moisture content of the grains, percent;

Mi = initial moisture content of the grains, percent;

Me = equilibrium moisture content of the grains, percent;

The equilibrium moisture content of the rice grains was determined by the equation proposed by Henderson-Thompson (Fontana, 1986) for rice grains paddy, described below:

$$Me=0{,}01\left(\frac{\ln(1-RH)}{0{,}000019187(T+51{,}161)}\right)^{0{,}409} \quad (2)$$

Where:

Me = equilibrium moisture content, percent;

RH = relative humidity of the drying air, percent;

T = grains mass temperature, °C.

The models used to describe the drying kinetics of paddy rice grains are shown in Table 1. These are the main mathematical models used to describe the drying of paddy rice grains (Cihan et al., 2007; Hacıhafızoğlu et al., 2008; Meneghetti et al., 2012; Khanali et al., 2012; Pattanayak et al., 2019). Also, from other agricultural products, such as beans and soy (Melo et al., 2016; Botelho et al., 2018), as well as medicinal plants such as guaco, sage and aroeira (Radünz et al., 2010; Radünz et al., 2014; Goneli et al., 2014).

Table 1 Mathematical models used to describe the drying kinetics of paddy rice grains at different temperatures and using firewood with different moisture contents as fuel

Models	Equation	References
Midilli	$MR = a\times Exp(-k\times t^n)+(b\times t)$	Midilli et al. (2002)
Page	$MR = Exp(-k\times t^n)$	Page (1949)
Newton	$MR = Exp(-k\times t)$	O'Callaghan et al. (1971)
Exponential two terms	$MR = (a\times Exp(-k\times t))+((1-a)\times Exp(-k\times a\times t))$	Togrul and Pehlivan (2003)
Two terms	$MR = (a\times Exp(-k0\times t))+(b\times Exp(-k1\times t))$	Henderson (1974)
Henderson andPabis	$MR = a\times Exp(-k\times t)$	Henderson and Pabis (1961)
Henderson andPabis	$MR = (a\times Exp(-k\times t))+(b\times Exp(-k0\times t))+(c\times Exp(-k1\times t))$	Karathanos (1999)
Diffusion approximation	$MR = (a\times Exp(-k\times t))+((1-a)\times Exp(-k\times b\times t))$	Sharaf-Elden et al. (1980)
Wang and Singh	$MR = 1+(a\times t)+(b\times t^2)$	Wang and Singh (1978)
Verma	$MR = (a\times Exp(-k\times t))+((1-a)\times Exp(-k1\times t))$	Verma et al. (1985)
Logarithmic	$MR = (a\times Exp(-k\times t))+c$	Akpinar and Bicer (2005)
Logistic	$MR = (a0/1)\times(a\times Exp(k\times t))$	Chandra and Singh (1995)

Note: MR= moisture ratio; k, k0, k1 = constants of drying; a, a0, b, n, c = constants of the equations

For the models adjustment to the experimental data, a non-linear regression analysis was performed, using the Gauss-Newton method, and the model parameters were estimated as a function of drying time, using the mean values observed in the two repetitions of each drying condition. The statistical software used to perform the analyzes was Statística® 10.0.

The choice of the model with the best fitness and representation of the drying process for the different conditions studied was based on the adjusted coefficient of determination ($r^2\geq0.95$), the mean relative error ($P\leq10\%$), the estimated mean error (SE) and waste distribution (biased or random). The equations used to determine the mean relative and estimated error are described below:

$$P=\frac{100}{n}\sum_{i-1}^{n}\frac{y-y0}{y} \quad (3)$$

$$SE=\sqrt{\frac{\sum_{i-1}^{n}(y-y0)^2}{df}} \quad (4)$$

On what:

P = mean relative error, in percentage

SE = estimated mean error, in decimal

y = observed value

y0 = value calculated by model

n = number of observations

df = degrees of freedom od model, ie, number of observations minus the number of model parameters.

3 Results and discussion

After drying, rice grains from different drying conditions had moisture contents between 12.2% and 12.3% w.b. The drying temperature directly involved the drying time, being observed for the drying air temperature of 65°C the shortest drying time (5.5 h) and for the temperature of 55°C the longest time (6.5 h) (Figure 1). The firewood moisture content did not influence the drying time. This result may be related to the fact that the amount of water evaporated from wet firewood at the beginning of burning is not able to significantly increase the relative humidity of the drying air. Thus, even with the decrease in temperature at the beginning of the burning of wet firewood, the air has a high capacity for removing water from the grains, therefore, not interfering with the drying time.

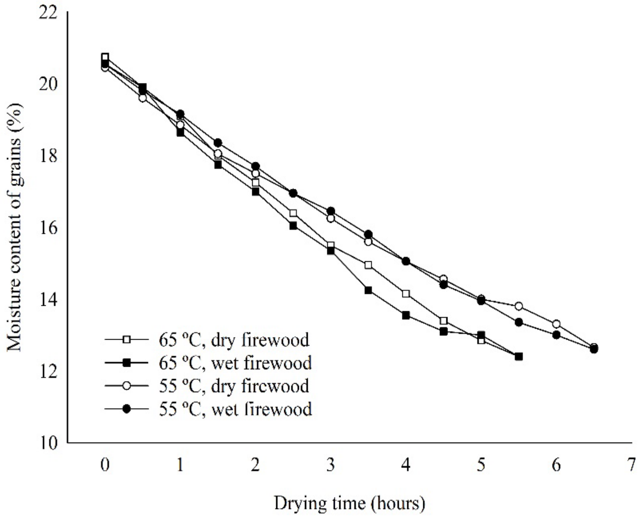

Figure 1 Moisture content of paddy rice grains, IRGA 424 RI cultivar, during drying with different drying air temperatures (55°C to 65°C) and using dry and wet firewood (12% and 32%) as fuel

The average grain mass temperatures for the conditions of 55°C and 65ºC were 35.1°C and 37.3ºC, respectively. The maximum temperatures reached at each drying temperature were 40.5°C and 42°C for 55°C and 65°C, respectively (Figure 2).

The grain mass temperature increased over the drying time for both temperatures and firewood moisture contents. This result is expected due to the different water removal rates throughout the drying process, which are characterized by the rapid removal of free water in the initial drying period, culminating in lower grain temperature, since most of the energy supplied by the air is being dissipated with the water removed. As the drying time goes by, the water removal rate decreases due to the reduction in the free water content inside the grains, resulting in a smaller amount of evaporated water and grains mass heating. (Portella and Eichelberger, 2001).

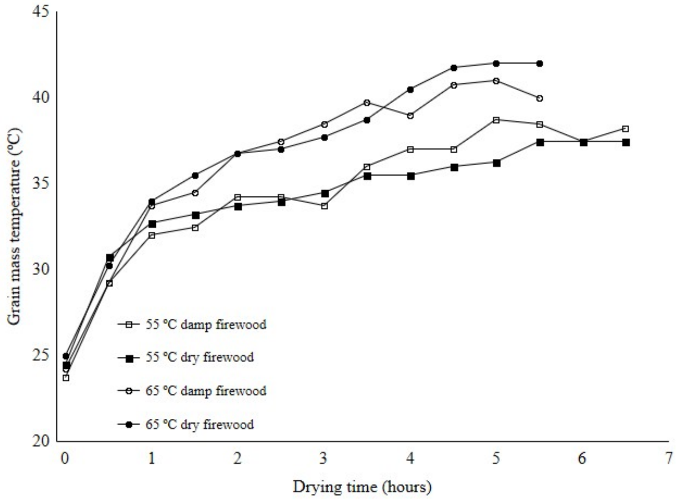

Figure 2 Grain mass temperature, cultivar IRGA 424 RI, during drying with different drying air temperatures (55°C to 65°C) and using dry and wet firewood (12% and 32%) as fuel

Table 2 shows the coefficient of determination, mean relative error, mean estimated error and the residuals randomness obtained for each mathematical model tested in each drying condition.

Table 2 Coefficient of determination (r^2), mean relative error (P), estimated mean error (SE), residuals randomness (RR) of the mathematical models tested for the drying kinetics prediction of paddy rice grains.

Drying	Mathematical model	r^2	P	SE	RR*
55ºC Dry firewood	Midilli	0.999	0.884	0.011	R
	Page	0.999	0.864	0.016	R
	Newton	0.999	0.997	0.029	B
	Exponential two terms	0.999	0.870	0.014	B
	Two terms	0.999	0.877	0.011	R
	Henderson and Pabis	0.999	0.936	0.018	B
	Henderson and Pabis modified	0.968	5.582	0.064	B
	Diffusion approximation	0.999	0.876	0.010	R
	Wang and Singh	0.999	0.983	0.020	R
	Verma	0.939	9.133	0.109	B
	Logarithmic	0.999	0.8785	0.0140	B
	Logistic	0.999	0.9364	0.0151	B
	Midilli	0.999	0.465	0.004	R
	Page	0.999	0.686	0.005	B
	Newton	0.998	1.603	0.011	B

55ºC Wet firewood	Exponential two terms	0.998	1.603	0.012	B
	Two terms	0.999	0.547	0.004	R
	Henderson andPabis	0.998	1.349	0.010	B
	Henderson and Pabis modificado	0.992	2.923	0.029	B
	Diffusion approximation	0.999	0.554	0.005	R
	Wang and Singh	0.999	0.498	0.004	R
	Verma	0.940	9.481	0.072	B
	Logarithmic	0.999	0.486	0.004	R
	Logistic	0.998	1.349	0.010	B
65ºC Dry firewood	Midilli	0.999	0.490	0.004	R
	Page	0.999	0.437	0.004	R
	Newton	0.999	0.869	0.007	B
	Exponential two terms	0.999	0.870	0.008	B
	Two terms	0.999	0.473	0.005	R
	Henderson and Pabis	0.999	0.666	0.006	R
	Henderson and Pabis modificado	0.994	2.508	0.027	B
	Diffusion approximation	0.999	0.478	0.006	R
	Wang and Singh	0.999	0.462	0.005	R
	Verma	0.860	13.83	0.110	B
	Logarithmic	0.999	0.474	0.005	R
	Logistic	0.999	0.666	0.006	R
65ºC Wet firewood	Midilli	0.998	1.423	0.012	R
	Page	0.997	1.446	0.012	R
	Newton	0.997	1.581	0.012	B
	Exponencial de dois termos	0.997	1.581	0.014	B
	Two terms	0.998	1.531	0.013	R
	Henderson and Pabis	0.998	1.475	0.012	R
	Henderson and Pabis modificado	0.994	2.545	0.026	B
	Diffusion approximation	0.997	1.485	0.015	B
	Wang and Singh	0.998	1.391	0.012	B
	Verma	0.832	15.61	0.123	B
	Logarithmic	0.998	1.460	0.013	R
	Logistic	0.998	1.475	0.013	R

Note: *B= biased; R= random.

According to the data presented in Table 2, all tested models obtained coefficients of determination above 99%, being considered satisfactory to describe the drying process of paddy rice grains under the different conditions studied, according to Madamba et al. (1996), except for the model proposed by Verma, which presented coefficient of determination values below 99% in all drying conditions and, therefore, was not considered satisfactory to describe the drying behavior. In addition, for drying at an air temperature of 55ºC and using dry firewood, the modified model proposed by Henderson and Pabis did not obtain a satisfactory coefficient of determination (r^2>0.99), and was not considered adequate to describe drying under these conditions.

The mean relative error values obtained by all mathematical models tested were less than 10%, which is considered satisfactory according to Mohapatra and Rao (2005), except for the model proposed by Verma, which presented mean relative error values greater than 10%, for drying at a temperature of 65ºC, regardless of the firewood moisture content. Regarding the estimated mean error, all tested models presented values with low magnitude. However, the model proposed by Midilli had the lowest magnitudes among the models tested in all drying conditions evaluated, presenting the best fitness to the experimental data to describe the drying process of paddy rice grains under the conditions in which the study was carried out.

As for the residuals randomness, the model proposed by Midilli demonstrated a satisfactory fitness, with a random distribution of residuals for all drying conditions studied (Figure 3). According to Afonso Júnior and Corrêa (1999), the residual dispersion graph indicates the quality of the model's adjustment to the experimental data, that is, the closer the residual values are to zero, the greater the predictive quality of the tested model.

Furthermore, the random distribution of residuals in the graph indicates that the model was not biased.

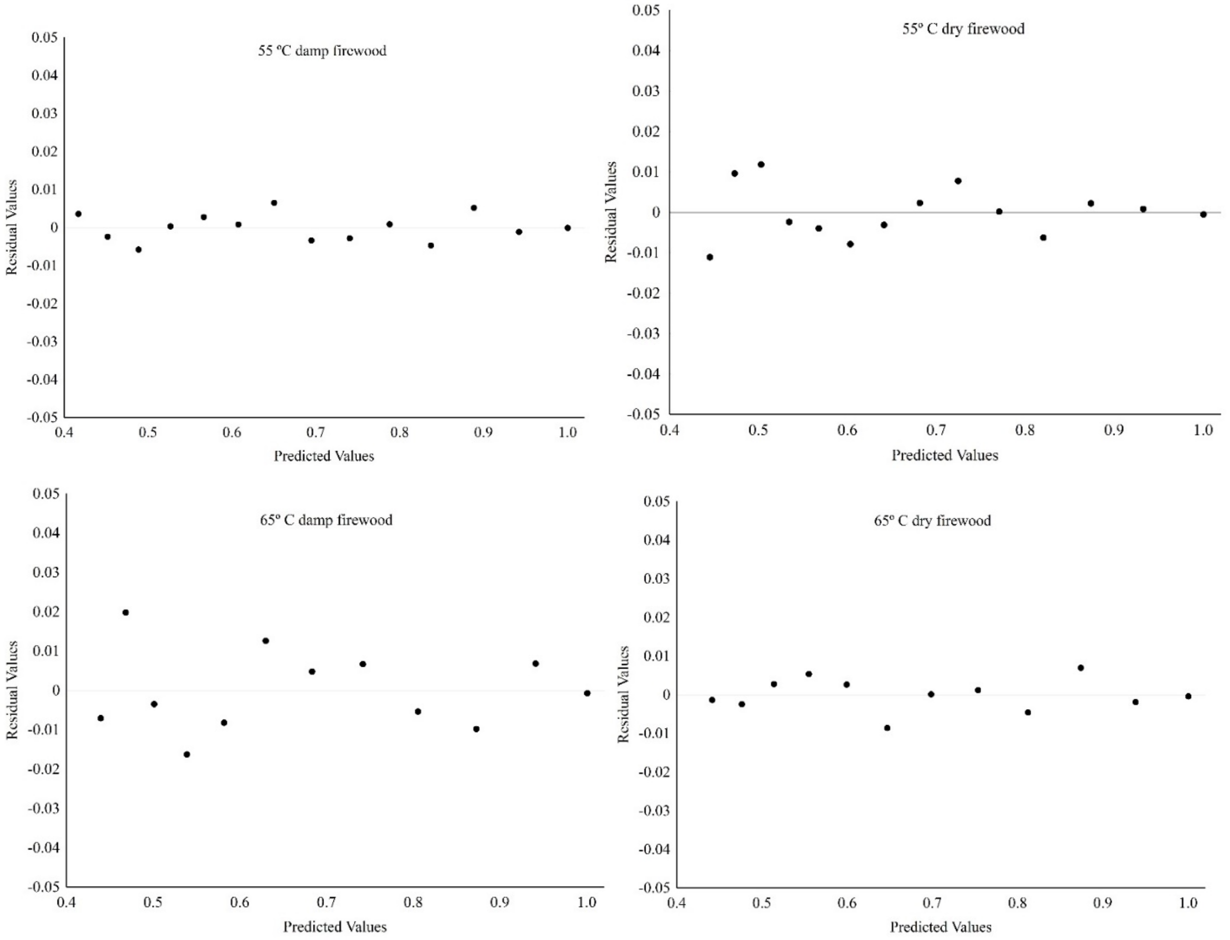

Figure 3 Distribution of residuals for the model proposed by Midilli for drying of paddy rice grains at different drying air temperatures, using dry and wet firewood as fuel

Thus, considering the statistical results described above, the mathematical model that best fitness to describe the kinetics of drying of paddy rice grains, for temperatures of 55ºC and 65ºC and using dry and wet firewood as fuel, is the model proposed by Midilli.

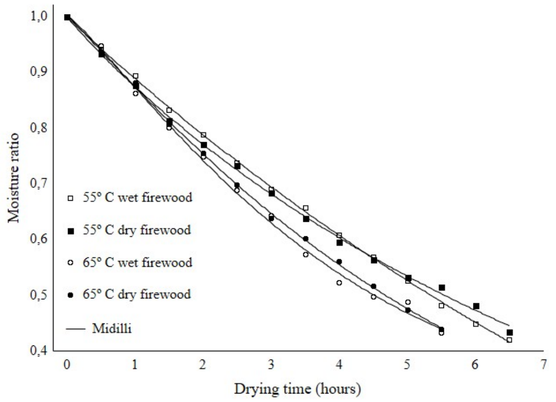

Figure 4 Drying kinetics curves estimated by the model proposed by Midilli for drying of paddy rice grains, cultivar IRGA 424 RI, with drying air temperature of 55ºC and 65ºC and using dry and wet firewood as fuel

Figure 4 shows the drying curves for the different conditions studied according to the model proposed by Midilli, as well as the experimental data obtained.

Table 4 Estimated parameters by the proposed model by Midilli for the rice grains, IRGA 424 RI, cultivar drying kinetics in different temperatures of the drying air

	Parameters			
Drying	a	k	n	b
55ºC Dry firewood	1.00	0.13	0.94	-0.0025
55ºC Wet firewood	1.00	-0.017	1.38	-0.13
65ºC Dry firewood	1.00	0.14	1.08	0.0050
65ºC Wet firewood	1.00	0.16	1.15	0.023

k= constant of drying; a, b, n = constants of the equations.

Table 4 shows the parameter values estimated by the model proposed by Midilli for each drying condition studied.

The results obtained are in agreement with Cihan et al. (2007) and Meneghetti et al. (2012), who considered the model proposed by Midilli the most adequate to describe the intermittent drying of paddy rice grains. Khanali et al. (2012) and Pattanayak et al. (2019) considered this model as the most adequate to describe the drying of rice grains in a fluidized bed at different temperatures. Also, Hacıhafızoğlu et al. (2008) found that the model proposed by Midilli was satisfactory to describe the drying of rice grains in a thin layer, using different temperatures.

4 Conclusions

Drying time is inversely proportional to the drying air temperature.

Regardless of the drying air temperature, the firewood moisture content does not change the drying time.

The grain mass temperature increases throughout the drying process, being proportional to the drying air temperature.

The firewood moisture content does not influence the grain mass temperature.

According to the statistical analysis performed, the model proposed by Midilli presents a satisfactory fitness to predict the intermittent drying of paddy rice grains at different drying air temperatures and using dry and wet firewood as fuel.

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References

Afonso Júnior, P. C., and P. C. Corrêa. 1999. Comparação de modelos matemáticos para descrição da cinética de secagem em camada fina de sementes de feijão. *Revista Brasileira de Engenharia Agrícola e Ambiental*, 3(3): 349-353.

Akpinar, E. K., and Y. Bicer. 2005. Modelling of the drying of eggplants in thin-layers. *International Journal of Food Science and Technology*, 40(3): 1-9.

Botelho, F. M., R. H. Hoscher, M. R. Hauth, and S. C. C. Botelho. 2018. Cinética de secagem de grãos de soja: influência varietal. *Revista Engenharia na Agricultura*, 26(1): 13-25.

Brasil. Ministério da Agricultura, Pecuária e Abastecimento. 2009. *Regras Para Análise De Sementes*. Brasília, Brasil: MAPA/SDA/ACS.

Chandra, P. K., and R. P. Singh. 1995. *Applied Numerical Methods for Food and Agricultural Engineers*. Boca Raton: CRC Press.

Cihan, A., K. Kahveci, and O. Hacıhafızog˘lu. 2007. Modelling of intermittent drying of thin layer rough rice. *Journal of Food Engineering*, 79(1): 293–298.

CONAB (Companhia Nacional de Abastecimento). 2021. *Acompanhamento Da Safra Brasileira De Grãos*, 8(9): safra 2020/21, nono levantamento.

Fontana, C. 1986. *Propriedades Físicas E Térmicas Do Arroz*. Santa Maria: Editora UFSM.

Gatto, D. A., E. J. Santini, C. R. Haselein, and M. A. Durlo. 2003, Características da lenha produzida na região da quarta colônia de imigração italiana do Rio Grande Do Sul. *Ciência Florestal,* 13(2): 7-16.

Goneli, A. L. D., P. C. Corrêa, O. Resende, and S. A. R. Neto. 2007. Study of moisture diffusion in wheat grain drying. *Ciência e Tecnologia de Alimentos*, 27(1): 135-140.

Goneli, A. L. D., M. C. Vieira, H. C. B. Vilhasanti, and A. A. Gonçalves. 2014. Modelagem matemática e difusividade efetiva de folhas de aroeira durante a secagem. *Pesquisa Agropecuária Tropical*, 44(1): 56-64.

Hacıhafızoğlu, O., A. Cihan, and K. Kahveci. 2008. Mathematical modelling of drying of thin layer rough rice. *Food and Bioproducts Processing*, 86(1): 268–275.

Henderson, S. M. 1974. Progress in developing the thin layer drying equation. *Transactions of the ASAE*, 17(6): 1167-1172.

Henderson, S. M., and S. Pabis. 1961. Grain drying theory I. Temperature effect on drying coefficient. *Journal of Agriculture Engineering Research*, 6(3): 169-174.

Karathanos, V. T. 1999. Determination of water content of dried fruits by drying kinetics. *Journal of Food Engineering*, 39(4): 337-344.

Khanali, M., S. Rafiee, A. Jafari, S. H. Hashemabadi, and A. Banisharif. 2012. Mathematical modeling of fluidized bed drying of rough rice (*Oryza sativa* L.) grain. *Journal of Agricultural Technology*, 8(3): 795-810.

Madamba, P. S., R. H. Driscoll, and K. A. Buckle. 1996. The thin-layer drying characteristics of garlic slices. *Journal of Food Engineering*, 29(1): 75-93.

Melo, P. C., I. A. Devilla, J. M. Caetano, V. B. S. X. Reis, A. M. Antunes, and M. M. Santos. 2016. Modelagem matemática das curvas de secagem de grãos de feijão carioca. *Agrária*, 11(3): 247-252.

Meneghetti, V. L., E. Aosani, J. C. Rocha, M. Oliveira, M. C. Elias, and R. S. Pohndorf. 2012. Modelos matemáticos para a secagem intermitente de arroz em casca. *Revista Brasileira de Engenharia Agrícola e Ambiental*, 16(10): 115-1120.

Midilli, A., H. Kucuk, and Z. A. Yapar. 2002. New model for single-layer drying. *Drying Technology*, 20(7): 1503-1513.

Mohapatra, D., and P. S. Rao. 2005. A thin layer drying model of parboiled wheat. *Journal of Food Engineering*, 66(1): 513-518.

O'Callaghan, J. R., D. J. Menzies, and P. H. Bailey. 1971. Digital simulation of agricultural dryer performance. *Journal of Agricultural Engineering Research*, 16(3): 223-244.

Page, G. E. 1949. Factors influencing the maximum rates of air drying shelled corn in thin layers. M.S. thesis, Mechanical Engineering Dept., Purdue University, West Lafayette.

Pattanayak, B., S. S. Mohapatra, and H. C. Das. 2019. Mathematical modelling for low temperature batch drying of paddy using fluidised bed technology. *International Journal of Mathematical Modelling and Numerical Optimisation*, 9(1): 89-103.

Portella, J. A., and L. Eichelberger. 2001. *Secagem de Grãos*. Passo Fundo, Brasil: Embrapa Trigo.

Radünz, L. L., E. C. Melo, R. P. Rocha, F. F. Barbosa, R. H. S. Santos, and P. A. Berbet. 2014. Avaliação das curvas de secagem de guaco (*Mikania glomerata* Spreng.) em secador de bandejas. *Revista Brasileira de Plantas Meicinais*, 16(2): 378-387.

Radünz, L. L., A. J. Mossi, C. A. Zakrzevski, A. S. Amaral, and L. Grassmann. 2010. Análise da cinética de secagem de folhas de sálvia. *Revista Brasileira de Engenharia Agrícola e Ambiental*, 14(9): 979-986.

Resende, O., E. R. Costa, W. D. Quequeto, L. M. Costa, D. E. C. Oliveira, S. A. V. Tfouni, F. M. L. Gomes, J. R. Quirino, and R. R. Lima. 2021. Quality of corn grains subjected to drying using direct-fired furnace fed with eucalyptus chips and firewood. Available at: https://www.scielo.br/j/cta/a/btWFMN7PHf9pZyvbTK63m3C/abstract/?lang=en. Accepted 09 February 2021.

Sharaf-Elden, Y. I., J. L. Blaisdell, and M. Y. Hamdy. 1980. A model for ear corn drying. *Transactions of the ASAE*, 5(4): 1261-1265.

Simoneit, B. R. T. 2002. Biomass burning — a review of organic tracers for smoke from incomplete combustion. *Applied Geochemistry*, 17(3): 129-162.

Togrul, I. T., and D. Pehlivan. 2003. Modelling of drying kinetics of single apricot. *Journal of Food Engineering*, 58(1): 23-32.

Verma, L. R., R. A. Bucklin, J. B. Endan, and F. T. Wratten. 1985. Effects of drying air parameters on rice drying models. *Transactions of the ASAE*, 28(1): 296-301.

USDA. 2021.*World Agricultural Production*. Washington: USDA.

Wang, C. Y., and R. P. Singh. 1978. Use of variable equilibrium moisture content in modeling rice drying. *Transactions of the ASAE*, 11(6): 668-672.