Maejo International Journal of
Energy and Environmental Communication

ARTICLE

Mathematical model of germinated paddy drying

Hathaichanok Netkham[1,*], Supawan Tirawanichakul[2], Sirinuch Chindaruksa[3] and Yutthana Tirawanichakul[4]

[1] Sustainable Energy Management, Department of Environmental Management, Faculty of Environmental Management, Prince of Songkla University, Hat Yai, Songkla, 90110 Thailand.
[2] Department of Chemical Engineering, Faculty of Engineering, Prince of Songkla University, Hat Yai, Songkla, 90110 Thailand.
[3] Department of Physics, Faculty of Science, Naresuan University, Phitsanulok 65000, Thailand
[4] Plasma and Energy Technology Research Laboratory, Department of Physics, Faculty of Science, Prince of Songkla University, Hat Yai, Songkla, 90110 Thailand.
*Corresponding author, *E-mail address*: hathaichanok_6.1@hotmail.com

ARTICLE INFOR

Received 25th January 2019
Accepted 22nd March 2019

Keywords:
Germinated paddy
Infrared
Mathematical model.

ABSTRACT

The objective of this research was to predict the moisture content of Sang Yod germinated paddy with infrared radiation power value of 1,000 watts at 60, 80 and 100 °C and hot air temperatures of velocity 1.1 m/s at 60, 80 and 100°C using empirical model. In this research, the moisture content of the dried samples was compared with the moisture content of the drying using the empirical model. The results showed that Verma model was most suitable to describe the drying behavior of germinated paddy at 60, 80 and 100 °C drying temperature when dried with infrared and hot air.

1. Introduction

Germinated brown rice have beneficial than white rice, as it is rich in fibre, iron, vitamins and minerals. These components will not be removed during the milling process. There are also contains more bioactive components, such as ferulic acid, γ-oryzanol, and gamma aminobutyric acid. However, germinated brown rice processes cause high moisture around 50-60 % dry-basic. Therefore, it must be reduced moisture by drying for storage and maintaining quality (Senadeera et al., 2003). Beside germinated paddy is more difficult to dry and more required more energy than paddy. There are several techniques for drying process such as solar, cabinet, rotary, fluidized bed, microwave, infrared drying, etc. Infrared drying is an effective method of dehydration. Infrared drying is a heat transfer by radiation between heating element and product surface. The heat energy is directly transferred to the product without the need of an intermedium. During the drying the absorptivity of the dried material decreases and its reflectivity and transmissivity increases, because of water content decreases in it. The absorptivity, the skin depth and the transmissivity are dependent on the density and on the wavelength of IR heating and on the properties of irradiated materials. Mathematical model of the drying behaviour can be better control of drying and to achieve high quality product. Therefore, mathematical model also has been widely used for analysis of drying behaviour of agriculture (Meisami-asl et al., 2009). The major objectives of the present study were to study the drying behaviour of germinated paddy in an infrared and hot air dryer at different heat sources and the drying air temperatures and

Nomenclature and Abbreviation	
IR	Infrared radiation
HA	Hot air
MR	Moisture ratio
RMSE	Root mean square error
M_t	The moisture content at time t
M_e	The equilibrium moisture content
M_i	The initial moisture content
$X_{p,i}$	The predicted value of data,
$X_{e,i}$	The experimental value of data

evaluate mathematical model of this drying configuration to predict the germinated brown rice drying time based on measures of error deviation from experimental data.

2. Materials and methods

2.1 Materials

The paddy varieties Sang Yod were obtained from the Rice Research Institute in Phatthalung Province, Thailand. The paddy varieties were cleaned. Then paddy was soaked in water for 24 h at room temperature. In during soaked, water was changed every 4 h. And then the germinated paddy sample was incubated at 24 h (Jirapa et al., 2016). After that it appears a small sprout at rice germ with a length of about 0.5-1 mm. The germinated paddy was steamed at 95±5°C for 30 min (Ohtsubo et al., 2005). And the last the germinated paddy was placed in ambient air before drying. The moisture content of the germinated paddy was determined using the AOAC 2000 method that the preparation germinated paddy shows in the Figure 1.

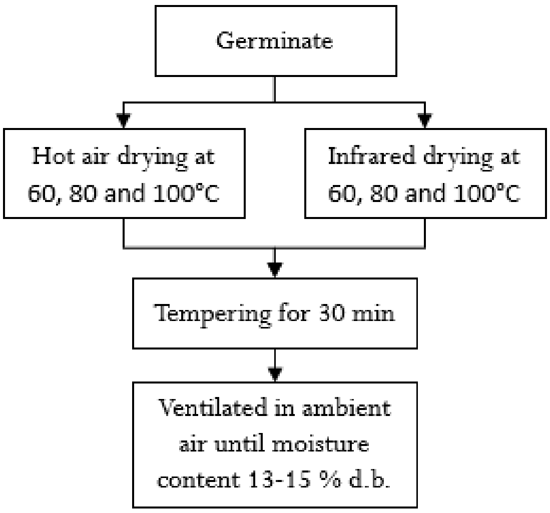


Figure 1. Experimental drying of germination paddy

2.2 Experimental

In the present study, the germinated paddy rice was tray-dried with hot air (HA) convection and infrared radiation (IR) using a tray-drying system (PSU-TRD-08-2) which was composed of 1-10 kW electrical heater units and electric infrared rod, a centrifugal fan driven by a 1.5 hp motor and a temperature controlling unit as illustrated in Figure 2. The experiments were carried out under the condition of drying temperature ranging of 60 to 100°C, inlet air flow rate of 1.0±0.2 m/s, IR power of 1,000 W. In each experiment, the 500 g samples of germinated paddy were weighed and put on a perforated tray in the drying chamber. The average initial moisture content of the rice sample was in the range of 55±1 and 49±1% dry-basis. The sample was dried until the desired final moisture content reached to 22±2% dry-basis. The germinated paddy sample was then taken off the drying chamber and ventilated by aeration until the safe moisture content of dried germinated paddy was about 14-16% dry-basis for prolonging shelf-life (Soponronnarit, 1997).

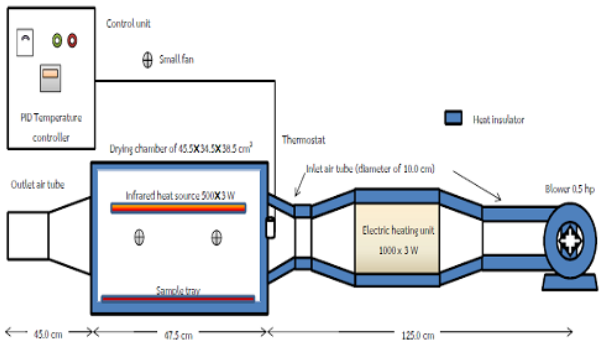


Figure 2. Thermal energy tray dryer

Table 1. Mathematical model of drying curves. (Midilli and Kucuk, 2003; Tirawanichakul et al., 2009; Nuthong, et al., 2011; Naderinezhad, et al., 2016).

2.3 Mathematical modelling for thin layer drying

The moisture ratio (MR) of germinated paddy samples during drying experiments was calculated using Eq. (1).

$$MR = \frac{M_t - M_e}{M_i - M_e} \quad \text{.........} \ (1)$$

Where MR is the moisture ratio, M_t is the moisture content at time t (kg water/kg dry matter); M_i is the initial moisture content (kg water/kg dry matter); M_e is the equilibrium moisture content (kg water/kg dry matter). The experimental data were fitted with nine mathematical models as detailed in Table I. The relationship between the drying constant and drying air parameters were evaluated by using multiple linear regression analyses.

Name of model	Model equation
Newton	MR= exp(-kt)
Page	MR = exp(-k(t^n))
Henderson and Pabis	MR = aexp(-kt)
Logarithmic	MR = aexp(-kt) + b
Two-term exponential	MR = aexp(-kt) + (1-a)exp(-kat)
Approximation of diffusion	MR = aexp(-kt) + (1-a)exp(-kbt)
Verma et al.	MR = aexp(-k1t) + (1-a) exp(-k_2t)
Midilli et al.	MR = aexp(-k(t^n)) + bt
Logistic	MR = a / (1+exp(kt))

Note: a, b, c, k and n mean arbitrary constant in simulated drying equation and k was also represented in linear function of drying temperature (in °C).

The suitability of equations and selected rediction method for moisture ratio (MR) of germinated paddy were compared and evaluated for determining the best fit equation using coefficient of determination (R^2) and root mean square error (RMSE). The higher R^2 value and lower RMSE value were used as the standard for goodness of fit (Vanichbuncha., 2016).

$$R^2 = 1 - \frac{\sum_{i=1}^{N} (X_{p,i} - X_{e,i})^2}{\sum_{i=1}^{N} (X_{p,i} - \overline{X})^2}$$

$$RMSE = \left[\frac{1}{N} \sum_{i=1}^{N} (X_{p,i} - X_{e,i})^2 \right]^{\frac{1}{2}}$$

Where;

X is the average of the experimental values,

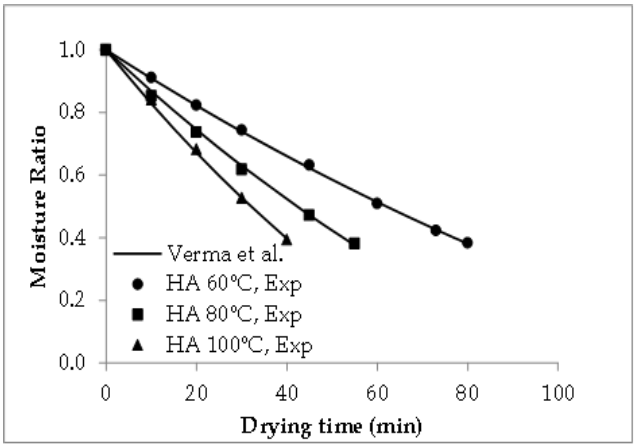
$X_{p,i}$ is the predicted value of data,

$X_{e,i}$ is the experimental value of data,

N is the number of experimental points.

3. Results and discussion

The effect of the temperature drying is shown in Figure 3. The result indicated that drying at high temperature decreases the moisture content (dry basis).



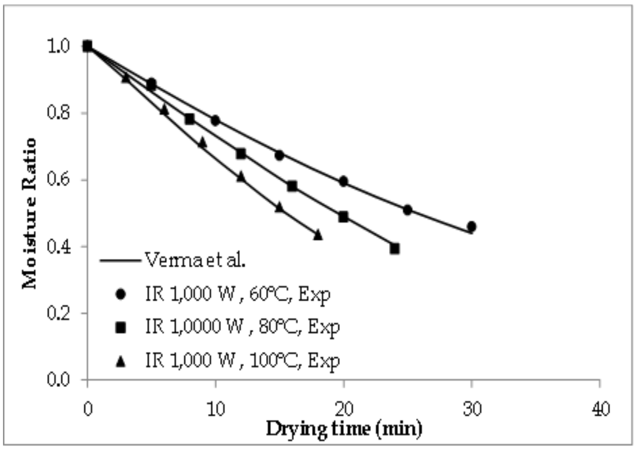


Figure 3. Comparison of the experimental and predicted moisture ratio of Sang Yod germinated paddy at drying temperatures of 60-100°C, average air velocity of 1.1 m/s and initial moisture content 47-51% dry-basis

The nine mathematical models were curve-fitted to the experimental data of drying parameter (drying temperature, drying time). To evaluate the best fit model R^2 and RMSE of paddy were comparatively studied using these mathematical models. The simulated empirical drying models and their drying constant were shown in the table 2 and 3. The result show that Verma et al. is the best fit model for hot air drying and infrared drying.

Table 2. Model constants statistical parameters for the hot air drying process of Sang Yod germinated paddy

Model	Content	R^2	RMSE
Newton	k=-0.0043+0.00026T	0.9914	0.0199
Page	k=-0.0041+0.00017T, n=1.1625	0.9984	0.0086
Henderson and Pabis	k=-0.0044+0.00027T, a=1.0179	0.9931	0.0177
Logarithmic	k=0.0248+814.8624T, a=1.9059, b=-0.9056	0.9989	0.0071
Two-term exponential	k=-39655.1+2369.6T, a=1.09$\times 10^{-7}$	0.9914	0.0199
Approximation of diffusion	k=-0.0082+0.0005T, a=-21.0624, b=0.9729	0.9986	0.0079
Verma et al.	k_1=-0.00082+0.00006T, k_2=-0.00067+0.00005T, a=-20.5014,	0.9989	0.0070
Midilli et al.	k=-0.0062+0.0002T, a=0.9977, b=-0.0016,n= 1.0878	0.9987	0.0074
Logistic	k=-0.0071+0.00042T, a=2.0008	0.9987	0.0075

Note: a, b, c, k and n mean arbitrary constant in simulated drying equation and k was also represented in linear function of drying temperature (in °C)

Table 3. Model constants statistical parameters for infrared drying process of Sang Yod germinated paddy

Model	Content	R^2	RMSE
Newton	k=0.0029+0.00039T	0.9864	0.0226
Page	k=-0.0020+0.00028T, n=1.1885	0.9961	0.1021
Henderson and Pabis	k=0.0031+0.00041T, a=1.0242	0.9900	0.1093
Logarithmic	k=-0.0000282+599.6812T, a=2245.71, b=2246.70	0.9915	0.0154
Two-term exponential	k=0.0029+0.00039T, a=1.006	0.9863	0.0208
Approximation of diffusion	k=0.0004+0.0001T, a=-23.835, b=1.137	0.9943	0.0117
Verma et al.	k_1=-0.2473+0.00551T, k_2=-0.0034+0.00059T, a=-0.1755,	0.9985	0.0089
Midilli et al.	k=0.0013+0.0002T, a=0.9985, b=0.0057, n=1.3101	0.9973	0.0113
Logistic	k=0.0038+0.0007T, a=2.0158	0.9953	0.0132

4. Conclusions

The research effect of difference heat source for drying germinated brown rice product can be summarized by the overview into the following;

1. When the drying temperature increased makes the drying rate increased and the drying time decreased.

2. Infrared drying has higher drying rate than hot air drying.

3. The moisture content decreases as the drying time and temperature increase.

4. When analyzing the suitable model the results shown that model of Verma et al. can be predicting the drying behavior of paddy germinated as close to the experiment.The experiments can be concluded: an optimum condition of germinated paddy drying was infrared drying at drying temperature 100°C. Because can be save energy and good quality of rice: head rice yield and texture.

Acknowledgements

The authors would like to sincere thanks to the Department of chemistry, Faculty of Engineering and Department of Physics, Faculty of Science School Prince of Songkla University for their supports place of experiment. Energy Policy and Planning Office Ministry of Energy and PSU graduate for supports their financial.

Conflicts of interest

There are no conflicts to declare.

References

AOAC., 2000. Official Method of Analysis, 16th Ed, the Association of Official Analytical Chemists. Inc. Arling-ton, Virginia, USA.

Diamante, L.M., Ihns, R., Savage, G.P., Vanhanen, L. 2010. A new mathematical model for thin layer drying of fruits. Journal International Food Science and Technology 45, 1956–1962.

Jirapa, K., Jarae, Y., Phanee R., Jirasak, K., 2016. Changes of bioactive components in germinated paddy rice. Journal International Food Research 23(1), 229-236.

Midilli, A., Kucuk, H., 2003. Mathematical modelling of thin layer drying of pistachio by using solar energy. Journal Energy conversion and Management 44, 1111-1122.

Meisami-asl, E., Rafiee, S., Keyhani, A., Tabatabaefar, A. 2009. Mathematical modeling of moisture content of apple slices (var.Golab) during drying. Pakistan Journal of Nutrition 8, 804–809

Naderinezhad, S., Etesami, N., Najafabady, A.P., Falavarjani, M.G., 2016. Mathematical modeling of drying of potato slices in a forced convective dryer based on important parameters. Journal Food Science and Nutrition 4, 110-118

Nuthong, P., Achariyaviriya, A., Namsanguan, K., Achariyaviriya, S., 2011. Kinetics and modeling of whole longan with combined infrared and hot air, Journal Food Engineering 102, 233-239.

Ohtsubo, K., Suzuki, K., Yasui Y., Kasumi, T., 2005. Bio-functional components in the processed pre-germinated brown rice by a twin-screw extruder. Journal Food Compos Anal 18, 303–316

Senadeera, W., Bhandari, B.R., Young, G., Wijesinghe, B., 2003. Influence of shapes of selected vegetable materials on drying kinetics during fluidized bed drying. Journal Food Engineering 58, 277–283.

Soponronnarit, S., 1997. Grains Drying and Some Food, Bangkok, Thailand: King Mongkut's University of Technology Thonburi, 338 pages.

Tirawanichakul, S., Linpo, P., Tirawanichakul, Y., 2009. Influence of infrared and heat convection on drying kinetics of shrimp and quality. Thai Journal of Physics 4, 116-120.

Vanichbuncha, K., 2016. Research Statistics Method, Bangkok, Thailand: Chulalongkorn University, 371 pages.