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Mathematical model of thin-layer drying of long pepper

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Abstract

This article presents the thin-layer drying of long peppers, which was conducted under controlled conditions of temperature by using a convective air dryer. The 1000 g of long peppers that the initial moisture content of 550% (d.b.) were dried for the temperature of 40, 50 and 60 °C, with the air flow velocity of 0.4, 0.7, 1 and 1.3 m s^{-1} until its final moisture content reach to 15% (d.b.). Besides the effects of drying air temperature and velocity, seven different thin-layer models were fitted to the experimental data of long peppers. The drying parameters of long peppers were found to be a function of drying air temperature. The Modified Handerson and Pabis model were revealed to be the best and it was followed by the Two-term model. Moisture diffusivities of long peppers have been determined experimentally and moisture diffusivities were found to increase with the increasing in drying air temperature. Moisture diffusivities of long peppers can be explained using an Arrhenius-type equation. A multilayer artificial neural network model was developed to predict the performance of this dryer. The predictive power of the model was found to be high after it was adequately trained. The Modified Handerson and Pabis model was found to be the best, followed by the two term model. The value of R^2 of the Modified Handerson and Pabis model was 0.9982-0.9996, indicating good fit and $RMSE$ were also good (0.28-0.71%). This study will be useful to optimize drying process parameters for commercial production of dried long pepper.

Keywords: ANN modeling; Long pepper; Thin-layer drying

1. Introduction

Long pepper (*Piper longum L.*) is a vine in the pepper family (*Piperaceae*) and therefore related to black pepper and betel leaves. It is native to South and Southeast Asia. The official name is piper chaba, known locally as Dee Plee pepper, and also known as Thai long pepper. In Ayurveda the root is used as a carminative, tonic to the liver, stomachic, emmenagogue, aborti-facient, aphrodisiac and fruit is said to possess haematinic, diuretic, digestive, general tonic properties, besides being useful in inflammation of the liver, pains in the joints, lumbago, snakebite, scorpion sting and night blindness [1]. Since freshly harvested long pepper have high moisture content. Therefore, drying removes the moisture content and preserves long pepper for longer periods of time.

Thin layer drying modeling is always used in order to understand and estimate the drying characteristics of agricultural products and overall improvement of the quality of the final product [2-4]. Modeling the drying kinetics and determining the drying time of agricultural products very important areas of drying. However, most production losses in the industry occur during drying. In order to minimize these losses it is necessary to optimize the drying conditions, machine design, and product quality. There is a need to identify and evaluate the drying mechanisms, theories, applications, and comparison of thin-layer drying models of agricultural products [5-8]. The objective of this study was to determine the effect of drying air temperature, velocity on the drying characteristics and to develop an artificial neural network (ANN) model to predict the drying characteristics of the long pepper obtained from Loei Province Thailand.

2. Materials and Methods

Materials

The long pepper samples were used in this experiment come from Loei Province, Thailand. They have initial moisture content about 550% (d.b.). The sample was stored in the refrigerator at temperature of 4 °C until the experiments were carried out. Before the experiments, the samples were removed from the refrigerator and allowed to reach room temperature (about 27 °C). Fig. 1 shows the schematic of thin layer drying of long peppers.

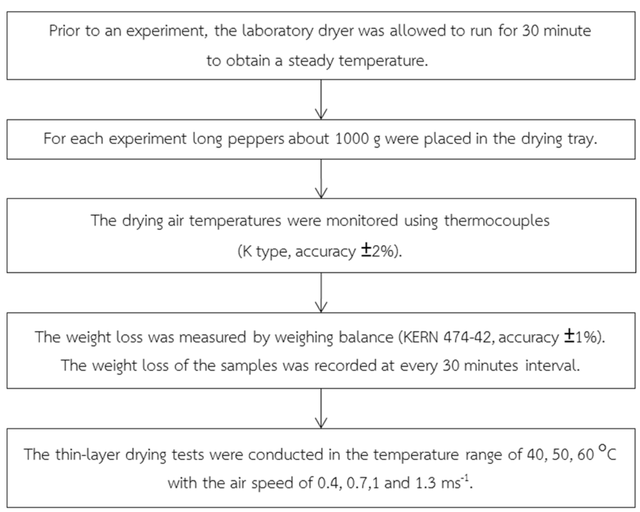


Fig. 1 Schematic of thin layer drying of long peppers

Drying equipment

A schematic diagram of this laboratory dryer is shown in Fig. 2. It consists of a blower, heaters, drying chamber, and instruments for measurement. The airflow rate was adjusted by the fan speed control. The heating system consisted of an electric heater placed inside the duct. The drying chamber temperature was adjusted by the heater power control. The homogeneity of air temperature and air flow was checked by using thermocouples and a hot wire anemometer. The moisture content during drying was estimated from the weight of the product samples and the estimated dried solid mass of the samples. At the end of the experimental drying, the exact dry solid mass of the product samples was determined by the oven method (103 °C for 24 hours, accuracy ± 0.5%).

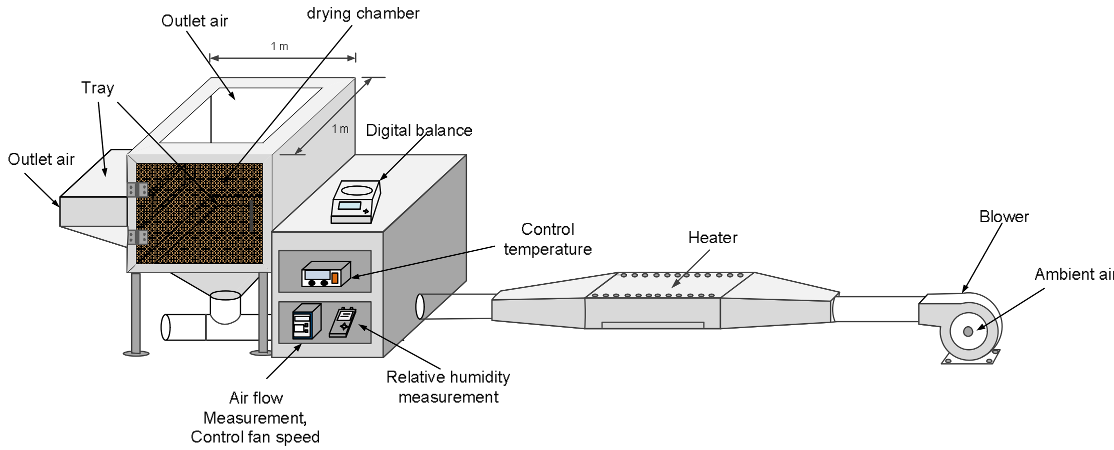


Fig. 2 Schematic diagram of the laboratory dryer

Table 1 Thin-layer mathematical drying models

Serial no	Model equation	Name of the model
1	$MR=e^{(-kt)}$	Newton
2	$MR=e^{(-kt^{n})}$	Page
3	$MR=ae^{(-kt)+(1-a)}e^{(-kat)}$	Two-term exponential
4	$MR=ae^{(-kt)}$	Handerson and Pabis
5	$MR=ae^{(-kt)+c}$	Logarithmic
6	$MR=ae^{(-kt)}+be^{(-gt)}$	Two-term
7	$MR=ae^{(-kt)}+be^{(-gt)}+ce^{(-pt)}$	Modifile Handerson and pabis

Mathematical modeling

Drying curves were fitted to the experimental data using seven different moisture ratio equations (Table 1). In these models, *MR* represents the dimensionless moisture ratio expressed as follow [9-13]:

$$MR = \frac{M_t - M_e}{M_0 - M_e} \quad (1)$$

where *MR* is the dimensionless moisture content ratio; and M_t, M_0 and M_e are the moisture content at any given time, the initial moisture content and the equilibrium moisture content, respectively. The values of M_e are relatively small compared with M_t or M_t/M_0 for long drying time [14]. Thus, moisture ratio can be simplified to $MR = M_t/M_0$. The non-linear least square regression analysis based on STATISTICA version 8 was used to estimate the parameters of the models (by fitting the model equations to experimental data). The coefficient of determination (R^2) is one of the primary criteria in order to evaluate the fit quality of selected models. In addition to R^2 and root mean square error (*RMSE*) are used to determine suitability of the fit. For the best fit, the R^2 value should be high and *RMSE* values should be low. *RMSE* and R^2 are defined as:

$$RMSE = \sqrt{\frac{\sum_{i=1}^{n}(MR_{pre,i} - MR_{exp,i})^2}{n}} \tag{2}$$

$$R^2 = 1 - \frac{Residual\ sum\ of\ squares}{Corrected\ total\ sum\ of\ squares} \tag{3}$$

where $MR_{exp,i}$ and $MR_{pre,i}$ are the moisture ratio derived from the experiment and the moisture ratio derived from the model. n is the number of observations.

Effective moisture diffusivity

The effective moisture diffusivity can be defined from Fick's second law of diffusion (Eq. 4), which describes the movement of moisture within the solid.

$$\frac{\partial M}{\partial t} = D_{eff}\nabla^2 M \tag{4}$$

where D_{eff} is the effective moisture diffusivity ($m^2\,s^{-1}$) representing the conductive term of all moisture transfer mechanisms, M is the moisture content (*dry basis*), and t is time (s). For the determination of moisture diffusivity, long peppers were considered as cylinder geometry. The equation for moisture diffusivity is expressed by.

$$\frac{M - M_e}{M_0 - M_e} = \sum_{n=1}^{\infty}\frac{4}{r^2(\boldsymbol{\alpha}_n)^2}\exp\left(-(\boldsymbol{\alpha}_n)^2\frac{D_{eff}t}{r^2}\right) \tag{5}$$

where D_{eff} is effective moisture diffusion coefficient (square meter per second), n is the number of terms of the Fourier series and r is the average radius of the long pepper, α_n is roots of the Bessel function of zero order, n= 1, 2, 3, ... and t is drying time.

Neural Network Modeling

The neurocomputing methods are shaped after biological neural functions and structure. As a result, they are generally known as artificial neural network (ANN). In this work, a multilayer ANN model of the thin-layer drying of long peppers were developed; the model has four-layered network. This network consists of a large number of processing elements, called neuron (Fig. 3).

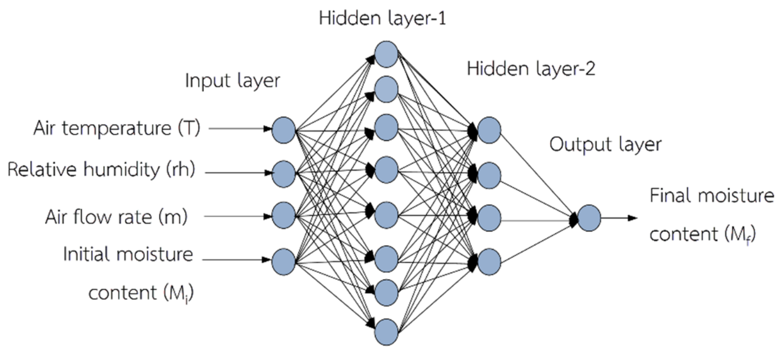
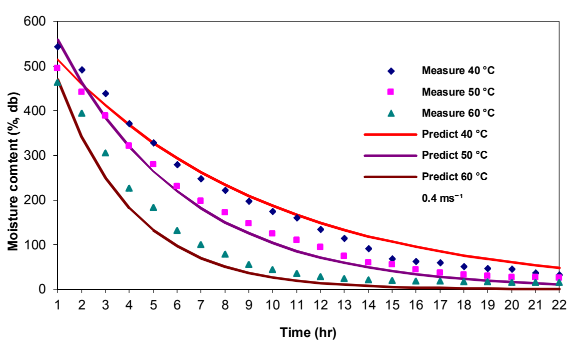


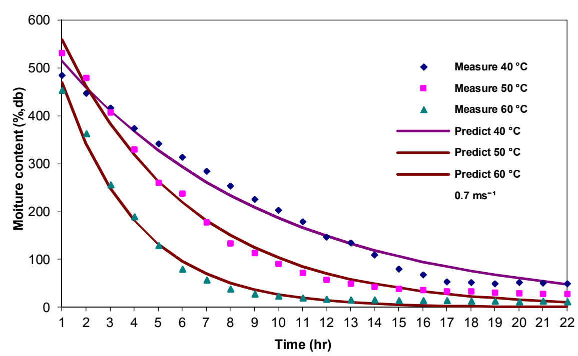
Fig. 3 The structure of the artificial neural network (4:8:4:1) of the thin-layer drying long peppers

The input layer of the model comprises four neurons which correspond to airflow rate ($\dot{m}$), air relative humidity (*RH*), air temperature (*T*) and initial moisture content (M_i). The output layer has one neuron which represents the final moisture content (M_f).

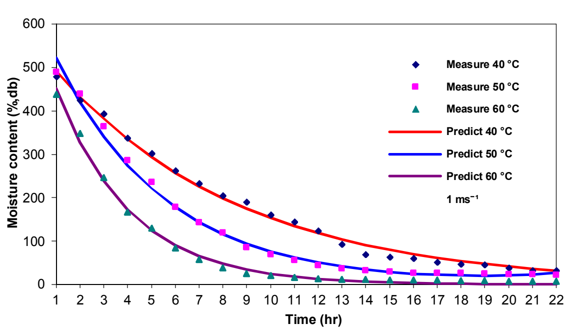
3. Results and Discussion



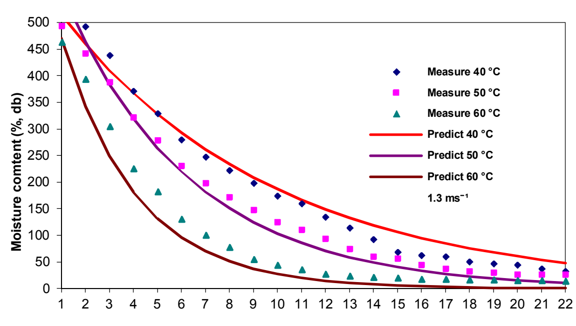
(a) Air velocity at 0.4 m s^{-1}



(b) Air velocity at 0.7 m s^{-1}



(c) Air velocity at 1 m s^{-1}



(d) Air velocity at 1.3 m s^{-1}

Fig. 4 Effect of drying air temperature and velocity on drying time for Modifile Handerson and Pabis model

The moisture content versus drying time and the variation of drying rate with moisture content at various air temperatures indicated that moisture content decreased exponentially with drying time. As a result, the time taken to reach the final moisture content is less, as shown in Fig. 4.

As can be seen at table 1, seven thin-layer mathematical drying models were fitted to the experimental data of moisture content of long peppers dried at different temperatures and velocity. The Modified Handerson and Pabis model was found to be the best, followed by the Two-term model. The value of R^2 of the Modified Handerson and Pabis model was 0.9982-0.9996,indicating good fit and *RMSE* were also good (0.28-0.71%).

Diffusivities of long peppers

The diffusivities of long peppers were found to be dependent on temperatures can be expressed as function of temperature by using the Arrhenius-type equations as follows:

$$D_{longpeper} = 5.47 \times 10^{-5} e^{\left[\frac{3627.58}{T_{ab}}\right]} \tag{6}$$

Fig. 5 presents the variations of moisture diffusivities of long peppers as functions of the reciprocal of absolute drying air temperature. The value of mean diffusivities of long peppers in the range 1.48×10^{-10} to 8.33×10^{-11} m^2s^{-1} found in this study.

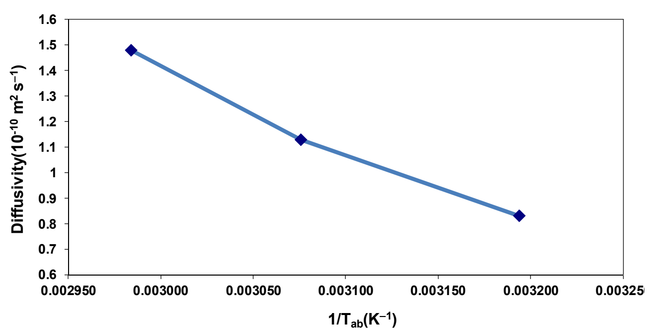


Fig. 5 Variations of moisture diffusivity of long peppers as a function of the reciprocal of absolute drying air temperature (T_{ab})

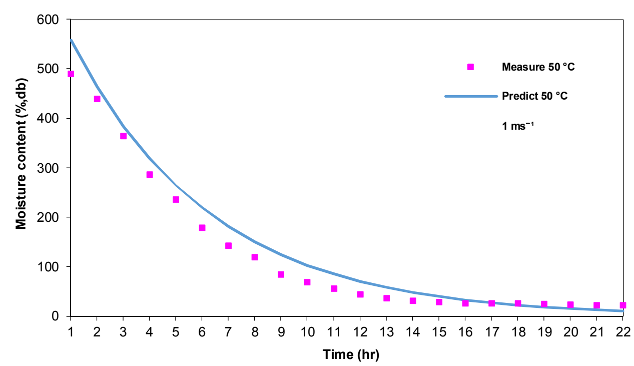


Fig. 6 Predicted and measured moisture contents of long peppers at the temperature of 50 °C with the air speed of 1 m s^{-1}.

Performance prediction by ANN model

The ANN model of the laboratory dryer developed for long peppers drying was trained with the experimental data from the experiments. The data from the experiment were reserved for testing the model. After 100,000 times of iteration step of training, the square sum of difference between the observed and the predicted output reached a significantly low level. The comparison between the model-predicted and measured moisture contents is shown in Fig. 6.

Drying of long pepper with 50°C temperature was found to be the best. The input parameters were optimized to 50°C with drying temperature in thin layer dryer for better response during drying of long pepper sample. From Fig. 6, it is found that the agreement between the predicted and measured moisture contents is good, the value of R^2 is 0.9284 and root mean square error (*RMSE*) is 0.004%. Thus, if the model is adequately trained, it can appropriately predict the performance of the thin-layer drying of long peppers.

4. Conclusion

Drying time decreased with increasing drying air temperature to reach a certain level of moisture content. The highest dehydration ratio was obtained at a drying air temperature of 60 °C. Similar results were reported for drying of green chilli [2] and potato slices [3]. The Modified Handerson and Pabis model could be used to explain moisture transfer in long peppers which gave the lowest value of RMSE and the highest value of R^2. This model can be used for drying air temperatures between 40, 50 and 60°C, velocities of 0.4, 0.7, 1 and 1.3 m s^{-1}.

Moisture diffusivities of long peppers have been determined experimentally and moisture diffusivities were found to increase with the increase in drying air temperature. Moisture diffusivities of long peppers can be explained using an Arrhenius-type equation. The value of mean diffusivities of long peppers in the range 1.48×10^{-10} to 8.33×10^{-11} m^2 s^{-1} found in this study.

The data for prediction by ANN model selected drying condition at the temperature of 50 °C with the air speed of 1 m s^{-1}. The ANN model was able to predict variations of moisture content quite well with determination coefficients (R^2) of 0.9284 for validation and testing. The prediction root mean square error (*RMSE*) was obtained as 0.004 for validation and testing. Results show good agreement between the experimental data on the one hand and mathematical models as well as the ANN model on the other.

5. Acknowledgement

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6. References

[1] M. Majeed, L. Prakash, The Medicinal Uses of Pepper, Int. Pep. N. 25(1) (2000) 23-31.

[2] T. Sadi, S. Meziane, Mathematical modelling, moisture diffusion and specific energy consumption of thin layer microwave drying of olive pomace, Int. Food. Res. J. 22(2) (2015) 494-501.

[3] M.A. Hossain, B.K. Bala, Thin-layer drying characteristics for green chilli, Dry. Technol. 20(2) (2002) 489–505.

[4] E.K. Akpinar, A. Midilli, Y. Bicer, Single layer drying behavior of potato slices in a convective cyclone dryer and mathematical modeling, Energ. Convers. Manage. 44 (2003) 1689–1705.

[5] M.A.S. Barrozo, D.J.M. Sartori, J.T. Freire, A study of the statistical discrimination of the drying kinetics equations, Food. Bioprod. Process. 82(C3) (2004) 219–225.

[6] C. Ertekin, O. Yaldiz, Drying of eggplant and selection of a suitable thin layer drying model, J. Food. Eng. 63 (2004) 349–359.

[7] R. Baini, T.A.G. Langrish, Choosing an appropriate drying model for intermittent and continuous drying of bananas, J. Food. Eng. 79 (2006) 330–343.

[8] I. Doymaz, Thin layer drying of spinach leaves in a convective dryer, J. Food. Process. Eng. 32(1) (2009) 112–125.

[9] A. Midilli, Determination of pistachio drying behaviour and condition in a solar drying, Inte, J. Energy. Res. 28 (2001) 715–725.

[10] A. Midilli, H. Kucuk, Z. Yaper, A new modelfor thin layer drying, Dry. Technol. 20 (2002) 1503–1513.

[11] O. Yaldiz, C. Ertekin, H.I. Uzun, Mathematical modeling of thin layer solar drying of sultan grapes, Energy. 26 (2001) 457–465.

[12] I.T. Togrul, S. Pehlivan, Modeling of thin layer drying kinetics of some fruits under open air sun drying process, J. Food. Eng. 65 (2004) 413–425.

[13] I. Doymaz, Thin layer drying behaviour of mint leaves, J. Food. Eng. 74 (2006) 370-375.

[14] N. A. Akgun, I. Doymaz, Modeling of olive cake thin-layer drying process, J. Food. Eng. 68(4) (2005) 455–461.