

MOISTURE DIFFUSIVITIES OF MACADAMIA NUTS FROM LOEI AGRICULTURAL RESEARCH AND DEVELOPMENT LOEI PROVINCE THAILAND

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Received: May 02, 2018; Revised: August 20, 2018; Accepted: August 24, 2018

Abstract

This article presents the thin-layer drying of macadamia nuts, which was conducted under controlled conditions of temperature by using a convective air dryer. The 2,000 g of macadamia nuts were dried for the temperature of 40, 50, and 60°C, with the air flow velocity of 0.2, 0.4, 0.6, 0.8, 1.0, and 1.2 m s⁻¹ until its final moisture content reach to 10% (d.b.). Besides the effects of drying air temperature and velocity, seven different thin-layer models were fitted to the experimental data of macadamia nuts. The Modified Handerson and Pabis model were revealed to be the best. The value of R² of the Modified Handerson and Pabis model was 0.9992-0.9986, indicating good fit and RMSE were also good (0.25-0.70%). Moisture diffusivities of macadamia nuts have been determined experimentally and moisture diffusivities were found to increase with the increasing in drying air temperature.

Keywords: Thin-layer drying, macadamia nuts, diffusivities.

Introduction

The macadamia (*Macadamia integrifolia*) is native to the coastal rain forest areas of southern Queensland and northern New South Wales in Australia (Stephenson and Cull, 1986). In Thailand, macadamia was introduced to grow in upland areas more than 55 years

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ago. Macadamia plantation areas are mainly located in northern Thailand. A major problem in production of macadamia is nut loss caused by mold and germination during processing and storage. Since freshly harvested macadamia nuts have a moisture content of about 33-37% dry basis (d.b.), hot air drying is typically used to reduce the kernel moisture content to 1.5% (d.b.) for long-term storage in ambient environment.

Thin layer drying modeling is always used in order to understand and estimate the drying characteristics of agricultural products (Hossain and Bala, 2002; Barrozo *et al.*, 2004; Ertkin and Yaldiz, 2004).

For proper understanding of transfer processes during drying and production of quality dried macadamia nuts, it is essential to know the thin-layer drying characteristics and the quality of the dried products. This study aims to evaluate thin-layer drying characteristics and moisture diffusivities of macadamia nuts obtained from macadamia plantation in Loei Agricultural Research and Development Loei Province Thailand.

Materials and Methods

Experimental Setup

The macadamia nuts used in this experiment come from Loei province in north eastern Thailand. They had initial moisture content about 35-37% (d.b.). The average diameter of the macadamia nuts was 2.0 cm. 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). The macadamia nuts were placed on a tray in a thin-layer in a laboratory dryer and dried under controlled conditions of temperature. The nuts were dried at the temperature of 40, 50, and 60°C with the air speed of 0.2, 0.4, 0.6, 0.8, 1.0, and 1.2 m s⁻¹.

Drying Equipment

A schematic diagram of this laboratory dryer is shown in Figure 1. 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 hotwire 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

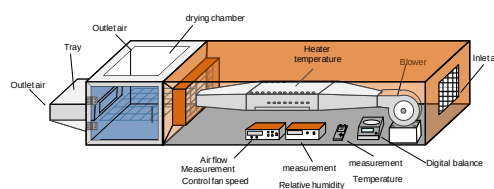


Figure 1. Schematic diagram of the laboratory dryer



(a)



(b)

Figure 2. (a) macadamia nuts fresh fruit (b) The macadamia nuts used in this experiment

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	$MR = ae^{(-kt)+(1-a)e^{(-kta)}}$	Two-term exponential
4	$MR = ae^{(-kt)}$	Handerson and Pabis
5	$MR = ae^{(-kt^n)}$	Logarithmic
6	$MR = ae^{(-kt)} + be^{(-gt)} + ce^{(-pt)}$	Modifile Handerson and Pabis
7	$MR = 1 + at + bt^2$	Wang and Singh

dry solid mass of the product samples was determined by the oven method (103°C for 24 h, accuracy $\pm 0.5\%$). The macadamia nuts used in this experiment from Loei Agricultural Research and Development Loei Province Thailand is shown in Figure 2.

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.

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. Thus, moisture ratio can be simplified to $MR = M_t/M_0$. The non-linear least square regression analysis based on STATISTICA version 13 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:

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

$$R^2 = \frac{1 - \text{Residual sum of squares}}{\text{Corrected total of squares}} \quad (2)$$

Results and Discussion

Drying Characteristics Of Macadamia Nuts

The changes in moisture contents with time for different drying air temperatures are shown in Figure 3. The final moisture content of samples dried under different conditions ranged from 4% to 10% (d.b.). The drying rate is higher for higher air temperature. As a result, the time taken to reach the final moisture content is less. Therefore, the drying air temperature has an important effect on the drying of macadamia nuts.

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 the Modified Handerson and Pabis model was found to be the best. The value of R^2 of the Modified Handerson and Pabis model was 0.9992-0.9986, indicating good fit and RMSE were also good (0.25-0.70%).

Effective Moisture Diffusivity

The effective moisture diffusivity can be defined from Fick's second law of diffusion (Equation 3), which describes the movement of moisture within the solid.

$$\frac{\partial M}{\partial t} = D_{eff} \nabla^2 M \quad (3)$$

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).

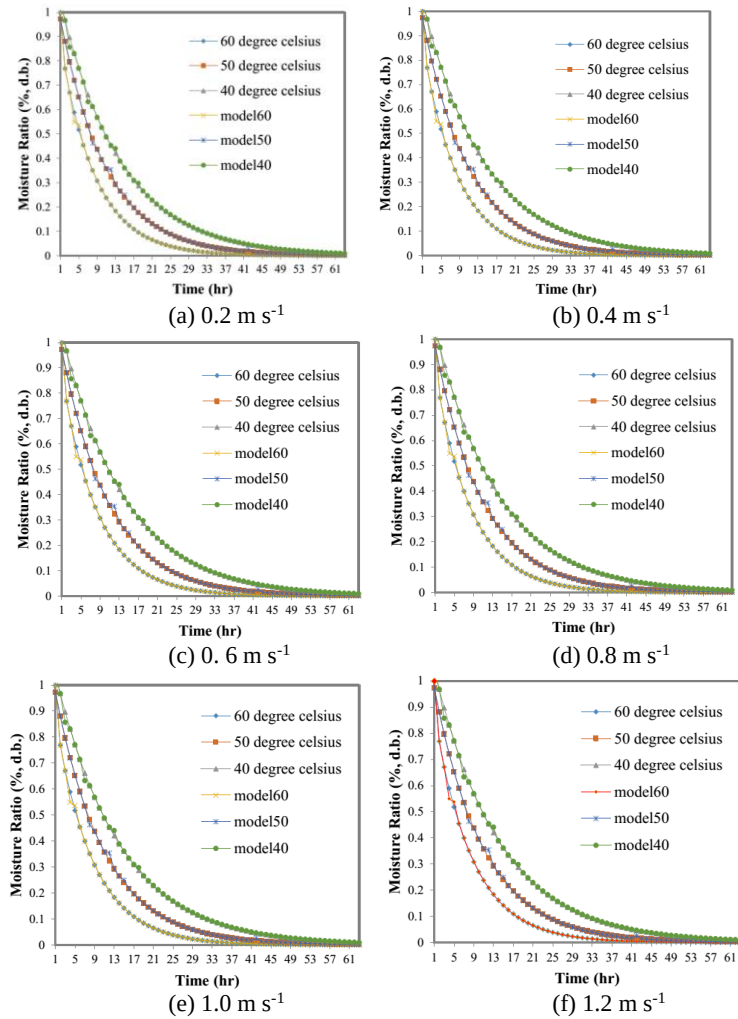


Figure 3. Effect of drying air temperature and velocity on drying time

For the determination of moisture diffusivity, macadamia nuts were considered as cylinder geometry. The equation for moisture diffusivity is expressed by.

$$\frac{M-M_e}{M_0-M_e} = \sum_{n=1}^{\infty} \frac{4}{r^2(\alpha_n)^2} \exp(-(\alpha_n)^2 \frac{D_{eff} t}{r^2}) \quad (4)$$

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 macadamia nuts, α_n

is roots of the Bessel function of zero order, $n=1, 2, 3, \dots$ and t is drying time (Hashemi *et al.*, 2009; Sadi and Meziane, 2015).

Diffusivities Of Macadamia Nuts

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

$$D_{eff} = 5.45 \times 10^{-6} e^{\left[\frac{2625}{T_{ab}} \right]} \quad (5)$$

The variations of moisture diffusivities of macadamia nuts as functions of the reciprocal of absolute drying air temperature is shown in Figure 4. The value of diffusivities of macadamia nuts in the range 1.42×10^{-10} to $0.83 \times 10^{-10} \text{ m}^2 \text{ s}^{-1}$ found in this study.

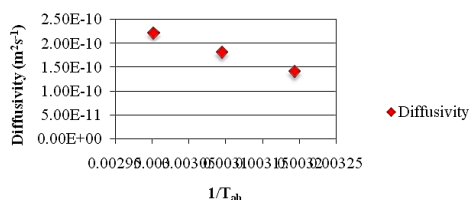


Figure 4. Variations of moisture diffusivity of macadamia nuts as a function of the reciprocal of absolute drying air temperature (T_{ah})

Conclusions

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. The Modified Henderson and Pabis model could be used to explain moisture transfer in macadamia nuts which gave the lowest value of RMSE and the highest value of R^2 . This model can be used for drying air temperatures between temperature of 40, 50, and 60°C, the air speed of 0.2, 0.4, 0.6, 0.8, 1.0, and 1.2 m s^{-1} . Moisture diffusivities of macadamia nuts have been determined experimentally and moisture diffusivities were found to increase with the increase in drying air temperature. Moisture diffusivities of macadamia nuts can be explained using an Arrhenius-type equation. The value of mean diffusivities of macadamia nuts in the range 1.42×10^{-10} to $0.83 \times 10^{-10} \text{ m}^2 \text{ s}^{-1}$ found in this study.

Acknowledgements

The author would like to thank Loei Rajabhat University for the financial support provided for this research work. The author also would like to thank Program of Physics, Department of Science, Faculty of Science and Technology, Loei Rajabhat University.

References

- Barrozo, M.A.S., Sartori, D.J.M., Freire, J.T. (2004). A study of the statistical discrimination of the drying kinetics equations. *Food. Bioprod. Process.*, 82(C3): 219 - 225.
- Ertekin, C., and Yaldiz, O. (2004). Drying of eggplant and selection of a suitable thin layer drying model. *J. Food Eng.*, 63:349-359.
- Hashemi, G., Mowla, D., and Kazemeini, M. (2009). Moisture diffusivity and shrinkage of broad beans during bulk drying in an inert medium fluidized bed dryer assisted by dielectric heating. *J. Food Eng.*, 92(3):331-338.
- Hossain, M.A. and Bala, B.K. (2002). Thin-layer drying characteristics for green Chilli. *Drying Technology.*, 20(2):489-505.
- Sadi, T. and Meziane, S. (2015). Mathematical modelling, moisture diffusion and specific energy consumption of thin layer microwave drying of olive pomace. *Int. Food Res. J.*, 22(2):494-501.
- Stephenson, R.A. and Cull, B.W. (1986). Vegetative flushing patterns of trees in south east Queensland. *Scientia Horticulturae* 30:53-62.