Mathematical Model Suitability for Thin-Layer Drying of Chiangda Herbal Tea (Gymnema inodorum Lour) under Modified Greenhouse Dryer

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Abstract. Chiangda or Gymnema is an herb from Thailand that has a long and varied history in traditional medicine. The objective of this study was to evaluate the influence of drying of gymnema with modified greenhouse dryer. Drying experiments were performed at an air temperature of 50°C was investigated in modified greenhouse dryer. The performance of the drying model was compared based on their correlation co-efficient ($R^2$), Root Mean Square Error (RMSE) and reduced Chi-Square ($\chi^2$) between the observed moisture ratios. The Wang and Singh models showed the best fit under modified greenhouse drying. The Wang and Singh equation was found to satisfactorily describe the drying behaviour of gymnema, with good agreement obtained with the experimental data the highest value of $R^2$ (0.9993) and the lowest values of MBE (-0.0007 - 0.00412), respectively. The moisture transfer from gymnema was describes by applied the Fick’s diffusion model. The effective moisture diffusivity varied from $9.28 \times 10^{-11}$ to $2.606 \times 10^{-10}$ m$^2$/s that increased with the temperature. An Arrhenius relation with an activation energy value of 24.91 kJ/mol expressed effect of temperature on the diffusivity.

1. Introduction

Chiangda or Gymnema (Gymnema inodorum Lour.) is one of the Thai local vegetables that grows in the northern part of Thailand [1]. It has been known with high nutritional values i.e., gymnemic acids, phytosterol and phenolic acid. Gymnema contains gymnemic acid, quercitol, lupeol, beta-amyrin and stigmasterol, all of which are thought to help the body maintain healthy blood glucose levels [2]. It is an herb from Thailand that has a long and varied history in traditional medicine. Chiangda herbal tea is of particular interest since it is an excellent source of nutrients and is easy to digest. The drying of gymnema leaves reduces moisture content and water activity, reducing microbial growth, enzymatic activity and chemical reactions, as well as saves transport and storage costs. The drying method influences the microstructure of the final product, as well as its physicochemical properties and rehydration capacity [3]. Gymnema leaves dried can be produced by various conventional drying methods, and the most common technique is solar and hot air drying which is a simple process. However, due to the low thermal conductivity and internal resistance to moisture transfer of food materials, this method always leads to low efficiency of heat transfer, and the quality of the dried product is generally reduced and often unsatisfactory [4]. Solar drying is the ancient method that is practiced everywhere for crop preservation. Solar drying is an effective method of utilizing energy of sun. Modified greenhouse
dryer is one of the simplest drying methods with low investment and operating costs. This technique was found to accelerate heat and mass transfer, leading to a shorter drying time [5]. Hamdi et al. (2018) reported that collector efficiency with a flow rate equal to 0.05 kg/s changed between 29.63% and 88.52% for the drying days. The moisture content of grape was reduced to 0.22 (g water/g dry matter) from its initial moisture content of 5.5 (g water/g dry matter) in 128 hr. [6], but there is little scientific literature about mathematical models of solar drying of gymnema. The mathematical models are needed in the design and operation of a dryer. However, the mathematical model for modified greenhouse dryer assisted thin-layer drying of gymnema could not be found in the literature. Therefore, this work aims to change of color, antioxidant activity, sensory evaluation and mathematical model suitability for thin-layer drying with modified greenhouse dryer.

2. Materials and methods

2.1 Material preparation: Gymnema was collected from the local market in Kosumpisai district, Mahasarakham Province, Thailand. Gymnema samples were cleaned and washed by tap water. After that, the gymnema leaves were sliced at 0.5x 4.0 cm. The samples were soaked in hot water (80°C) with a ratio 1:1.5 w/v for 10 min. The samples were roasted in an iron pan on low heat for 30 min. The moisture content after roasted was in the ranges of 50-70% (dry basis, d.b.).

2.2 Drying procedure: Modified greenhouse dryer on active mode was used in the Rajabhat Maha Sarakhm University, Thailand. The experimental such as temperature was specified to match the highest climatic air temperature in Thailand. Each experiment was replicated three times and the final product with moisture content of 3-5% (d.b.). The samples were stored at -20°C prior to analysis.

2.3 Mathematical Model: Drying curves were obtained for the gymnema leaves under condition drying of modified greenhouse dryer, air temperature and were fitted with five different models as shown in Table 1. The moisture ratio (MR) was estimated from the ratio (M - M0)/(M0 - Mc), using the final moisture content of dehydrated product as the equilibrium moisture content (M). M0 is initial moisture content and M is moisture content at any time, expressed on a dry basis.

### Table 1. Mathematical models for the drying of gymnema leaves

| Model name       | Model equation | Ref.               |
|------------------|----------------|--------------------|
| Newton           | X = exp(-k t)  | Koua et al., (2009) [7] |
| Page             | X = exp(-kt^n) | Basunia MA, Abe T.(2001). [8] |
| Henderson and Pabis | X = a*exp(-kt^n) | Koua et al., (2009) [7] |
| Wang and Singh   | X = 1 + at + bt^2 | Koua et al., (2009) [7] |
| Logarithmique    | X = a*exp(-kt) + c | Koua et al., (2009) [7] |

2.4 Correlation coefficients and error analyses: The coefficients of correlation (R²), efficiency model (EF), root mean square error (RMSE), mean bias error (MBE) and chi-square were used as the criteria for the accuracy of the model fit. The higher of the correlation coefficient, efficiency model, lower of the root mean square error and chi-square are to be considered for good fitting of the model. These coefficient values were calculated as follows:

\[
R^2 = 1 - \frac{\sum_{i=1}^{N}(X_{pre,i} - X_{exp,i})^2}{\sum_{i=1}^{N}(X_{pre,ave} - X_{pre,i})^2} \tag{1}
\]

\[
EF = \frac{\sum_{i=1}^{N}(X_{exp,i} - X_{exp,ave})^2 - \sum_{i=1}^{N}(X_{pre,i} - X_{exp,i})^2}{\sum_{i=1}^{N}(X_{exp,i} - X_{exp,ave})^2} \tag{2}
\]
\[
\text{RMSE} = \sqrt{\frac{1}{N} \sum_{i=1}^{N} (X_{\text{pre},i} - X_{\text{exp},i})^2}
\]  
(3)

\[
\text{MBE} = \frac{1}{N} \sum_{i=1}^{N} (X_{\text{pre},i} - X_{\text{exp},i})
\]  
(4)

where \(X_{\text{exp},i}\) is the ith experimental values, \(X_{\text{pre},i}\) is the ith predicted values, \(N\) is the number of observations and \(z\) is the number of constants.

2.5 Effective moisture diffusivity: The drying characteristics of biological products mostly in the falling rate period can be described using Fick’s second law of diffusion [9].

\[
\frac{\partial M}{\partial t} = \nabla \cdot (D_{\text{eff}} \nabla M)
\]  
(5)

where \(D_{\text{eff}}\) is effective moisture diffusivity (m\(^2\)/s) and \(M\) is moisture content (g water/g dry matter).

2.6 Physical properties: The moisture content was determined by drying triplicate samples in a hot air oven at 103°C for 72 hr. The color of samples was determined by a Hunter Lab colorimeter (MiniScan XE Plus, Hunter Associates Laboratory, Inc., USA). An antioxidant activity was determined by DPPH radical scavenging method [10].

3. Results and discussions
This study has focused on the mathematical models and qualities of gymnemic tea by modified greenhouse dryer. The experimentally investigated for gymnemic drying. The drying air temperature inside the solar dryer at 50°C. The moisture content of gymnemic was reduced to 3-5% (d.b.) in the modified greenhouse dryer took only 300 min. The numerical model based on Wang and Singh simulation was validated by showing that the numerical results show a good agreement with the experimental measurements. Therefore, the proposed numerical model will be used for optimization of dryer components and drying process.

Table 2. Mathematical models of moisture ratio according to drying time for gymnema on modified greenhouse dryer

| Model name         | Model coefficient | \(D_{\text{eff}}\) (m\(^2\)/s) | \(R^2\)  | RMSE    | MBE       |
|--------------------|-------------------|-------------------------------|----------|---------|-----------|
| Newton             | k = 0.1096        | 6.51 \times 10^{-11}         | 0.992    | 0.030   | -6.14x 10^{-3} |
|                    | k = 0.0615        | 9.28 \times 10^{-11}         | 0.991    | 0.027   | -6.39x 10^{-3} |
|                    | n = 1.1709        |                               |          |         |           |
| Page               | k = 0.1119        | 1.36 \times 10^{-10}         | 0.985    | 0.045   | -7.00x 10^{-3} |
|                    | a = 1.0489        |                               |          |         |           |
| Henderson and Pabis| k = 0.1119        | 2.60 \times 10^{-10}         | 0.999    | 0.015   | -4.12x 10^{-3} |
|                    | a = 0.9469        |                               |          |         |           |
|                    | b = 0.0431        |                               |          |         |           |
| Wang and Singh     | k = 0.1182        | 7.84 \times 10^{-11}         | 0.998    | 0.036   | -3.97x 10^{-3} |
|                    | a = 0.9614        |                               |          |         |           |
|                    | c = 0.0386        |                               |          |         |           |
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References
[1] Puttawarachai P, Chanrittisen T, Sritontip P and Kunsupa N 2016 Classification of Phak Chiang Da (Gymnema inodorum (Lour.) Decne) according to Leaf Morphology. Songklanakarin J. of Plant Sci., 3, Suppl. (III): M10/23-29
[2] Nair S. and R. Keshavachandran 2006 Genetic variability of chakkarakolli (Gymnena sylvestre R. Br.) in Kerala assessed using morphological and biochemical markers. J. of Tropical Agricul, 44, 64–67
[3] Seremet L, Botez E, Nistor, O 2016 Effect of different drying methods on moisture ratio and rehydration of pumpkin slices. Food Chem. 195, 104-109
[4] Xiaoyong Li R C, Luo T X, Molg T 2016 Leaf unfolding of Tibetan alpine meadows captures the arrival of monsoon rainfall. Sci. Reports, 6, 75-79
[5] Hamdi I, Kooli S, Farhat A 2018 Experimental investigation and economic evaluation of a new mixed-mode solar greenhouse dryer for drying of red pepper and grape. Renew. En, 77, 145-151
[6] Mediani A, Abas F, Tan C, Khatib A 2014 Effects of Different Drying Methods and Storage Time on Free Radical Scavenging Activity and Total Phenolic Content of Cosmos caudatus. Antioxidants, 3, 358-370
[7] Chanhan P and Kumar A 2016 Performance analysis of greenhouse dryer by using insulated north-wall under natural convection mode. Energy Re, 2, 107-116
[8] Prakash O and Kumar A 2015 Annual Performance of a Modified Greenhouse Dryer Under Passive Mode In No-Load Conditions. Inter. J. of Green Energy, 1091-1099
[9] Koua K, Fassinou W, Gbaha P. and Toure S 2009 Mathematical modelling of the thin layer solar drying of banana, mango and cassava. Energy, 34, 1594–1602
[10] Basunia MA Abe T 2001 Thin layer solar drying characteristics of rough rice under natural convection. J. of Food En, 47, 295–301
[11] Crank J 1975 The Mathematics of Diffusion. pp. 267-268 (2nd ed.). London: Oxford University Press.
[12] Benzie I and Strain J 1996 The Ferric Reducing Ability of Plasma (FRAP) as a measure of antioxidant power: The FRAP assay, J. of Anal. Biochem, 39, 70-76
[13] Lim J, Fujimaru T 2010 Evaluation of the Labeled Hedonic Scale under different Experimental Conditions. Food Quality and Prefer, 21: 521–530