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 (χ^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 9.28×10^{-11} to 2.606×10^{-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 h[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^{o}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 Sarakham 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 ^{o}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 $(M-M_e)/(M_0-M_e)$, using the final moisture content of dehydrated product as the equilibrium moisture content (M_e). M_0 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	$X_r = \exp(-k\ t)$	Koua et al., (2009) [7]
Page	$X_r = \exp(-k\ t^n)$	Basunia MA, Abe T.(2001). [8]
Henderson and Pabis	$X_r = a*\exp(-k\ t^n)$	Koua et al., (2009) [7]
Wang and Singh	$X_r = 1+ at + bt^2$	Koua et al., (2009) [7]
Logarithmique	$X_r = a*\exp(-k\ t)+c$	Koua et al., (2009) [7]

2.4 Correlation coefficients and error analyses : The coefficients of correlation (R^2), 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:

$$R^2 = 1 - \frac{\sum_{i=1}^{N}\left(X_{pre,i} - X_{exp,i}\right)^2}{\sum_{i=1}^{N}\left(X_{pre,ave} - X_{pre,i}\right)^2} \quad (1)$$

$$EF = \frac{\sum_{i=1}^{N}\left(X_{expd,i} - X_{exp,ave}\right)^2 - \sum_{i=1}^{N}\left(X_{pre,i} - X_{exp,i}\right)^2}{\sum_{i=1}^{N}\left(X_{exp,i} - X_{exp,ave}\right)^2} \quad (2)$$

$$\mathrm{RMSE} = \sqrt{\frac{1}{N}\sum_{i=1}^{N}\left(X_{pre,i} - X_{exp,i}\right)^2} \quad (3)$$

$$\mathrm{MBE} = \frac{1}{N}\sum_{i=1}^{N}\left(X_{pre,i} - X_{exp,i}\right) \quad (4)$$

where $X_{exp,i}$ is the ith experimental values, $X_{pre,i}$ 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] .

$$\frac{\partial M}{\partial t} = \nabla.\left(D_{eff}\nabla M\right) \quad (5)$$

where D_{ff} 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, Henter Associates Laboratory, Inc., USA). An antioxidant activity was determined by DPPH radical scavenging method[10].

3. RESULTS AND DISCUSSIONS

The moisture content of gymnema tea in all drying treatment decreased exponentially by increasing time. The moisture content of sample can be reduced to 3-5% (d.b.) in 300 minutes for drying temperature of 50°C. The Wang et Singh equation was found to satisfactorily describe the drying behaviour of gymnema tea, with good agreement obtained with the experimental data the highest value of $R^2 = 0.999$ (Table 2). The moisture transfer from gymnema tea was describes by applied the Fick's diffusion model. The effective moisture diffusivity varied from 9.28×10^{-11} to 2.606×10^{-10} m^2/s and increased with the temperature. An Arrhenius relation with an activation energy value of 24.91 kJ/mol.

The results shown that the total color difference (ΔE) of gymnema tea was 5.21. The DPPH is a stable free radical and accepts an electron or hydrogen radical to become a stable diamagnetic molecule. The DPPH scavenging effect of gymnema tea at 50°C was 64.26 (% inhibition).

4. CONCLUTION

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 byshowing 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_{eff} (m^2/s)	R^2	RMSE	MBE
Newton	k = 0.1096	6.51 x 10^{-11}	0.992	0.030	-6.14x 10^{-3}
Page	k =0.0615 n =1.1709	9.28 x 10^{-11}	0.991	0.027	-6.39x 10^{-3}
Henderson and Pabis	k =0.1119 a =1.0489	1.36 x 10^{-10}	0.985	0.045	-7.00x 10^{-3}
Wang and Singh	a =0.9469 b =0.0431	2.60x 10^{-10}	0.999	0.015	-4.12x 10^{-3}
Logarithmique	k= 0.1182 a = 0.9614 c= 0.0386	7.84 x 10^{-11}	0.998	0.036	-3.97x 10^{-3}

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