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Effects of microwave power on the drying characteristics, color and phenolic content of *Spirogyra* sp.

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Abstract

This study aimed to determine the drying characteristics and qualities of *Spirogyra* sp. undergoing a laboratory-scale of the microwave drying. The time required to reduce moisture content of *Spirogyra* sp. from 8.54±0.17 to 0.10±0.02% g water/g dry matter at 2.5, 2.0, 1.5 and 0.8 W/g microwave power was 25, 34, 47 and 88 min, respectively. Thin layer drying models (Lewis, Page, logarithmic, Midilli *et al.* and Henderson and Pabis) were fitted to the experimental drying data in order to find the most suitable model describing the drying characteristics of *Spirogyra* sp. The logarithmic model showed an excellent fit at the most satisfactory level to predict drying behavior of the *Spirogyra* sp. because this model gave the highest coefficient of determination (R^2), the least chi-square (χ^2), and the lowest root mean square error (RMSE). The best quality in terms of color and phenolic content, associated with biological activity, were obtained in the drying period with 1.55 W/g microwave power. At this setting, it could be ensured that the best overall quality of dried *Spirogyra* sp. was chosen as the most appropriate technique for the alga microwave drying.

Key words: *Spirogyra* sp., microwave drying, drying model, phenolic content.

Introduction

Spirogyra sp. (Division Chlorophyta) is an edible freshwater macroalga, consumed as traditional food in the north and northeast of Thailand due to its high nutrient content (18.63% protein, 5.21% fat, 56.31% carbohydrate and 7.66% fiber) including vitamins, minerals and phenolic content [1]. The alga contains phenolic compounds which are the substances associated with biological activity [2]. The aqueous extracts of *Spirogyra* sp. exhibited in rats pharmacological effects, such as an antioxidant, anti-gastric ulcer, anti-inflammatory, antimutagenic and anti-diabetic activities, which suggested their value as therapeutic agents [1, 2]. Drying is an important method to preserve a wide variety of products, which reduces the water content and water activities in order to limit the growth of spoilage bacteria [3]. Some of the disadvantages of the common hot air drying are low energy efficiency and lengthy drying time, especially during the falling rate period [4]. On the other hand, microwave drying technique has distinct advantages compared with the conventional hot air drying and recently has been considered as an sufficient drying alternative without the effects during heat transferring. The microwave energy can penetrate directly into materials and induce volumetric heating inside the materials, therefore, the drying period and energy consumption is lower while the overall quality of product is significantly improved [5, 6].

The thin-layer equations contributed to the heat and mass transfer phenomena of *Spirogyra* sp. are required for designing new processes and improving existing commercial operations [7]. This study focused on the effects of microwave power levels on the drying characteristics, drying time, color properties, phenolic content and specific energy consumption of dried *Spirogyra* sp. undergoing laboratory-scale of the microwave drying. In addition to this, a proper mathematical model for thin-layer drying which can describe the drying characteristics of *Spirogyra* sp. was investigated.

Materials and Methods

Raw materials: Fresh *Spirogyra* sp. was purchased from a local supplier in Thailand, washed and stored at 4±0.5°C at refrigerator for about one day for equilibration of moisture. To determine the initial moisture content, sixty samples of 2.5 g were dried by hot air drying at 105±2°C (Memmert, Model:500/108I) for 24 h [8]. The mass was measured on an analytical balance (Sartorius, Model CP2245) with a precision of ±0.01 g. The initial moisture content of *Spirogyra* sp. was 8.54±0.17 g water/g dry matter as an average of the results obtained.

Drying equipment and drying procedure: A programmable microwave oven (Panasonic Model NN-S235WF) with a maximum output of 750 W was used for the experiment. The digital controller located on the microwave oven was used for adjusting the power level and drying time. Weight loss during drying process was recorded using a computer software data logger through a balance connected to a PC. A sample of 300 g of *Spirogyra* sp. was spread into a single layer on the 20 x 20 cm^2 ceramic tray. The sample was dried with four different microwave power levels of 0.77, 1.55, 2.00 and 2.50 W/g from initial moisture content of 8.54±0.17% g water/g dry matter until the final moisture content was about 0.10±0.02% g water/g dry matter.

Mathematical modeling: Moisture content data obtained from the drying experiments were converted into the dimensionless moisture ratio (MR). MR and drying rate (DR) were calculated using the following equations:

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

$$\mathrm{DR} = \frac{M_{t+dt} - M_t}{dt} \quad (2)$$

where M_i, M_t, M_e and M_{t+dt} are moisture content (g water/g dry matter) at initial, specific time, equilibrium and *t*+d*t*, respectively; t is drying time (min). Due to prolonged drying yielded, the equilibrium moisture content would be close to zero ($M_e = 0$) [9]. The best model describing the microwave drying behavior *of Spirogyra* sp. was selected by testing with 5 commonly used thin layer drying models provided in Table 1. The correlation coefficient (R^2) was one of the primary criteria for selecting the best fitted model expressing the drying curves of the *Spirogyra* sp. In addition to R^2, the chi-square (χ^2) and root mean square error (RMSE) were used to determine the consistency of the fit [4, 7, 10]. These statistical values can be calculated as follows:

$$RMSE = \sqrt{\frac{1}{N}\sum_{i=1}^{N}(MR_{\exp,i} - MR_{pred,i})^2} \quad (3)$$

$$\chi^2 = \frac{\sum (MR_{\exp,i} - MR_{pred,i})^2}{N - n_p} \quad (4)$$

where $MR_{\exp,i}$ is i^{th} moisture content observed experimentally; $MR_{pred,i}$ is i^{th} predicted moisture content; *N* and n_p represent the number of observation and constants, respectively.

Table 1. Mathematical models applied to the drying curves of *Spirogyra* sp.

Drying model name	Model	Reference
1. Lewis	$MR = \exp(-kt)$	7
2. Page	$MR = \exp(-kt^n)$	3
3. Logarithmic	$MR = a\exp(-kt) + c$	4
4. Midilli *et al.*	$MR = a\exp(-kt^n) + bt$	10
5. Henderson and Pabis	$MR = a\exp(-kt)$	10

Color measurements: The color of dried *Spirogyra* sp. was measured in the CIELAB color system using spectrophotometer (HunterLab ColorFlex Version 1.72, USA), and 3 parameters, *L** (lightness), *a** (redness/greenness) and *b** (yellowness/blueness) were measured with 5 replicates and the data was presented in an average. During drying process, the total color change (ΔE) was also calculated from the CIELAB color system using the following equation:

$$\Delta E = \sqrt{(L^*_t - L^*_0)^2 + (a^*_t - a^*_0)^2 + (b^*_t - b^*_0)^2} \quad (5)$$

where L^*_0, a^*_0, b^*_0 are the initial color measurements of fresh *Spirogyra* and L^*_t, a^*_t, b^*_t are the color measurements at a pre-specified time.

Determination of phenolic content: Total phenolic content (TPC) was measured using the Folin-Ciocalteu method; 0.1 ml of the sample solution in methanol was mixed with 0.75 ml of 10% Folin-Ciocalteu reagent and incubated at 37°C. After 5 min 0.75 ml of 6% sodium carbonate solution was added and allowed to stand for 30 min at 37°C and the color developed was measured at 750 nm. Results were compared to a gallic acid (GA) calibration curve [11] and expressed as mg GA/100 g dry matter.

Results and Discussion

Drying characteristics: The drying time required for *Spirogyra* sp. during microwave drying from the initial moisture contents of 8.54±0.17 to 0.10±0.02% g water/g dry matter was achieved in 25, 34, 47 and 88 min at 2.5, 2.0, 1.5 and 0.8 W/g of microwave power levels, respectively. As expected, the moisture ratio (MR) rapidly decreased at the beginning of the drying process, and then become gradually reduced afterwards. Relationships between MR and drying time under different microwave power levels during drying process are shown in Fig 1. The MR of *Spirogyra* sp. was reduced exponentially as the drying time increased. Drying rates were calculated using Equation (2) and the changes in drying rates according to moisture content are shown in Fig 2. Apparently, the drying rate continuously decreased over the time as the moisture content decreased, and the drying time increased. At higher microwave power, the drying time became lower because of increasing in water vapor pressure within *Spirogyra* sp., which resulted in higher moisture removal. The rate of moisture loss was higher at high microwave power and the total drying time was reduced substantially with the increase in the power levels. This is due to increasing of internal power energy and acceleration of water migration inside *Spirogyra* sp. Also, it was noted that the drying rate increased when the microwave power level was higher.

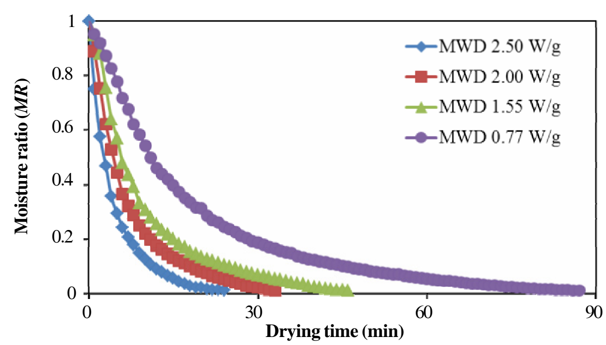

Figure 1. Drying curve of *Spirogyra* sp. during microwave drying process at different microwave power levels.

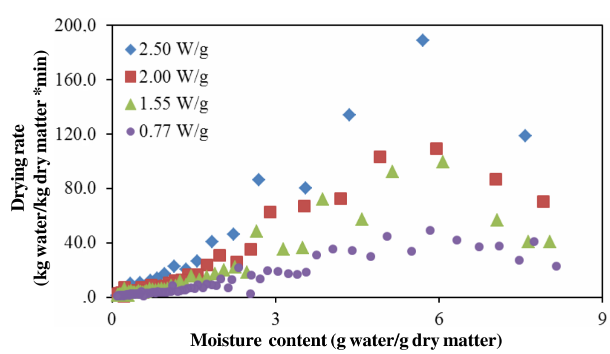

Figure 2. Drying rate of *Spirogyra* sp. during microwave drying process at different microwave power levels.

As a result, the higher microwave power of drying process led to higher moisture transferred rate. The influence of microwave power level on the drying rate was indicated in earlier researches, as *Gundelia tournefortii*[4], paddy rice [5] and okra [9].

Effect of microwave power levels on the color and phenolic content of spirogyra: Lightness (L*-value), greenness (negative a*-value) and yellowness (positive b*-value) of fresh *Spirogyra* sp. were 14.54, -3.37 and 15.34, respectively. After the microwave drying process, the lightness and yellowness of dried *Spirogyra* sp. were significantly increased, possibly because of chlorophyll degradation, and the obtained color was light greenyellow. If the lightness decreased and the redness increased after microwave drying, it would result in dark greenbrown color. Table 2 shows the results of color properties and phenolic content of *Spirogyra* sp. during microwave drying at different microwave power levels. A redness/greenness value (a^* value) was used as an indicator of chlorophyll content and color difference was marked by a total color difference (TCD) value. Microwave power of 1.55 W/g provided the lowest value of a^* and TCD which indicated the highest greenness value of *Spirogyra* sp. and the high content of remaining chlorophyll. This result is in accordance with the total phenolic content (TPC) analysis. The highest TPC of 1,764.14±21.78 GA mg/100 g dry weight was observed after microwave drying of *Spirogyra* sp. at 1.55 W/g. Although high drying rate was achieved during drying process at 2.0 and 2.50 W/g microwave power, a large amount of excess power was observed. The excess power affected the degradation of colorant and TPC. Similarly, although there was no excess power obtained by microwave drying at 0.77 W/g, the long-time drying also influenced the degradation of colorant and TPC. Therefore, optimal conditions, especially microwave power and drying time for microwave drying of *Spirogyra* sp. played an important role in quality controlling. Assawarachan and Noomhorm [10] also described the effect of microwave power on color and carotenoid degradation during microwave vacuum evaporation.

Mathematical modeling: The non-linear regression analysis was used to determine the suitable mathematical modeling that best described the microwave drying of *Spirogyra* sp. The average moisture contents of *Spirogyra* sp. were observed in g water/g dry matter during the drying at various different microwave power levels. Selected thin-layer drying models, as shown in Table 1, were fitted to drying curves and the equation parameters using non-linear least squares regression analysis [4, 7, 12]. The best model describing the thin layer drying characteristics of biomaterial during microwave drying was chosen as the one with the lowest chi square (χ^2), minimum values of root mean square error (*RMSE*) and the highest correlation coefficient (R^2). The parameters of empirical mathematical model (k, n, a and b) and statistical analysis results applied to these models by taking into consideration with all microwave power levels are given in Table 3. In all cases of this study, the value of R^2 was greater than 0.99 indicating satisfactorily a good fitting. For all experiments, the R^2, χ^2, and RMSE values of the models altered in the extent of 0.9936-0.9978, $2.58x10^{-4}$ - $8.39x10^{-4}$, and 0.0158-0.0287, respectively. The results indicated that among these five models, the proposed semi-empirical logarithmic model was most appropriate for prediction because it

Table 2. The CIELAB color properties and total phenolic content of *Spirogyra* sp. during microwave drying at 0.77 to 2.50 W/g.

Microwave Power Levels	CIELAB Color Properties				Total Phenolic Content (TPC)
	L^*-values	a^*-values	b^*-values	TCD	(GA mg/ 100 g)
0.77 W/g	33.96±3.68^a	1.73±0.20^a	20.04±2.73^a	17.91±4.09^a	1,484.52±32.79^a
1.55 W/g	36.12±1.22^b	1.52±0.17^b	27.96±2.61^b	16.39±3.41^b	1,764.14±21.78^b
2.00 W/g	34.36±2.51^a	1.70±0.19^{ab}	22.71±1.26^a	17.63±2.88^a	1,608.81±19.53^c
2.50 W/g	33.43±2.39^a	2.42±020^c	19.21±1.31^a	17.50±2.63^a	1,593.33±21.82^c

Data are expressed as the average ± standard deviation.

Table 3. Regression coefficients of thin layer drying models for *Spirogyra* sp. during microwave drying at 0.77 to 2.50 W/g.

Drying Model	Microwave Power Levels (W/g)	Empirical Drying Model Constants					Analytical Parameters		
		k	n	a	b	c	R^2	χ^2 ($x10^{-4}$)	*RMSE*
Lewis	0.77	0.055	-	-	-	-	0.9965	3.8816	0.0196
	1.55	0.100	-	-	-	-	0.9936	8.3954	0.0287
	2.00	0.138	-	-	-	-	0.9961	5.0521	0.0222
	2.50	0.215	-	-	-	-	0.9967	3.7493	0.0190
Page	0.77	0.062	0.962	-	-	-	0.9970	3.6283	0.0188
	1.55	0.097	1.015	-	-	-	0.9936	8.5245	0.0286
	2.00	0.141	0.992	-	-	-	0.9962	5.1951	0.0221
	2.50	0.228	0.966	-	-	-	0.9970	3.6801	0.0184
Logarithmic	0.77	0.061	-	1.011	-	0.025	0.9981	2.0569	0.0141
	1.55	0.116	-	1.039	-	0.027	0.9959	5.2697	0.0222
	2.00	0.155	-	1.017	-	0.024	0.9976	3.1989	0.0171
	2.50	0.233	-	1.003	-	0.019	0.9978	2.6655	0.0158
Midilli *et al.*	0.77	0.071	0.943	1.052	0.000	-	0.9978	2.6110	0.0158
	1.55	0.104	1.026	1.052	0.001	-	0.9951	6.5633	0.0245
	2.00	0.144	1.014	1.033	0.001	-	0.9973	3.7757	0.0183
	2.50	0.233	0.980	1.023	0.001	-	0.9972	3.8570	0.0181
Henderson and Pabis	0.77	0.056	-	1.014	-	-	0.9965	3.8358	0.0194
	1.55	0.105	-	1.045	-	-	0.9941	7.3299	0.0265
	2.00	0.142	-	1.024	-	-	0.9962	4.8131	0.0213
	2.50	0.217	-	1.009	-	-	0.9960	5.2625	0.0220

provided the highest R^2, while χ^2 and *RMSE* were lowest. According to these results, the semi-empirical logarithmic model was the most suitable model in describing the microwave drying behavior of *Spirogyra* sp. Earlier studies by some authors confirmed that the semi-empirical logarithmic model was also suitable for describing drying curve in many agriculture and biomaterials as well.

Conclusions

The effects of microwave power levels on drying characteristics and the quality of *Spirogyra* sp. during microwave drying process at different power levels were investigated based on the color properties and phenolic content. The optimum drying microwave power level was found to be 1.55 W/g judging by the comparison of quality results obtained from the different power levels. Considering from five thin layer drying models, the logarithmic model was best describing the microwave drying characteristics of *Spirogyra* sp.

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References

[1]Rattanapot, T., Mengumphan, K., Srimaroeng, C., Junthip, R. and Amornlerdpison, D. 2012. Antioxidant activity of *Spirogyra* sp. and effect of its supplementation on growth performance of tilapia in cage culture. J. Fish Tech. Res. **6**(2):23-34 (in Thai).

[2]Lailerd, N., Pongchaidecha, A., Amornlerdpison, D. and Peerapornpisal, Y. 2009. Beneficial effects of *Spirogyra neclecta* extract on glycemic and lipidemic status in streptozotocin-induced diabetic rats fed a diet enriched in fat. Annals of Nutrition and Metabolism **55**(S1):609.

[3]Pongtong, K., Assawarachan, R. and Noomhorm, A. 2011. Mathematical models for vacuum drying characteristics of pomegranate aril. Journal of Food Science and Engineering **1**(1):11-19.

[4]Evin, D. 2012. Thin layer drying kinetics of *Gundelia tournefortii* L. Food and Bioproducts Processing **90**:323-332.

[5]Assawarachan, R., Sripinyowanich, J., Theppadungporn, K. and Noomhorm, A. 2011. Drying paddy by microwave vibro-fluidized drying using single mode applicator. International Journal of Food, Agriculture & Environment **9**(2):50-54.

[6]Sagar, V. R. and Suresh Kumar, P. 2010. Recent advances in drying and dehydration of fruits and vegetables: A review. Journal Food Science and Technology **47**(1):15-26.

[7]McMinn, W. A. M. 2006. Thin-layer modeling of the convective, microwave, microwave-convective and microwave vacuum drying of lactose powder. Journal of Food Engineering **72**:113-123.

[8]AOAC 2005. Official Methods of Analysis of AOAC International, 18th Edition. In Horwitz, W. and Latimer, G.W. (eds). Current through Revision 2, 2007. Association of Official Analytical Chemists International, Gaithersburg, MA, USA.

[9]Dadal, G., Apar, D. K. and Özbek, B. 2007. Microwave drying kinetics of okra. Drying Technology **25**:917-924.

[10]Assawarachan, R. and Noomhorm, A. 2011. Mathematical models for vacuum microwave concentration behavior of pineapple juice. Journal of Food Process Engineering **34**(5):1485-1505.

[11]Sachindra, N. M., Airanthi, M. K. W. A., Hosokawk, M. and Miyashita, K. 2010. Radical scavenging and singlet oxygen quenching activity of extracts from Indian seaweeds. Journal of Food Science Technology **47**:94-99.

[12]Assawarachan, R. and Noomhorm, A. 2008. Effect of operating condition on the kinetic of color change of concentrated pineapple juice by microwave vacuum evaporation. International Journal of Food, Agriculture & Environment **6**(3&4):47-53.